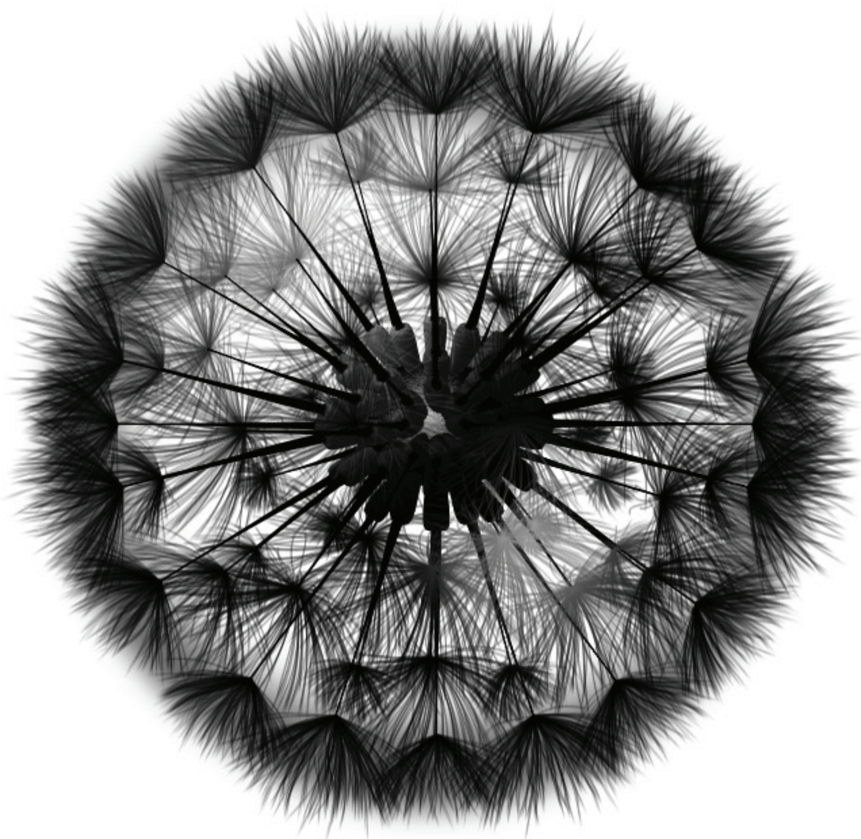
The Centre for Research on Inner City Health

THE BIO.DIASPORA PROJECT



An Analysis of Canada's Vulnerability to Emerging Infectious Disease Threats via the Global Airline Transportation Network

A Report Released by St. Michael's Hospital

Leading with Innovation
Serving with Compassion
ST. MICHAEL'S HOSPITAL
A teaching hospital affiliated with the University of Toronto

Information about The BIO.DIASPORA Project

can be found at www.biodiaspora.com

All inquiries and correspondence pertaining to

The BIO.DIASPORA Project should be directed to:

info@biodiaspora.com

TABLE OF CONTENTS

AUTHORS' ROLES & AFFILIATIONS

Kamran Khan MD, MPH, FRCPC
Project Leader

Scientist
Centre for Research on Inner City Health
Keenan Research Centre in the
Li Ka Shing Knowledge Institute of
St. Michael's Hospital

Scientist
MITACS Centre for Disease Modeling
York University

Staff Physician
Department of Medicine
Division of Infectious Diseases
St. Michael's Hospital

Assistant Professor
Department of Medicine
Division of Infectious Diseases
Department of Health Policy, Management and Evaluation
University of Toronto

Julien Arino MSc, PhD
Mathematical Modeling

Scientist
MITACS Centre for Disease Modeling
York University

Assistant Professor
Department of Mathematics
University of Manitoba

Felipe Calderon MSc
Network Analysis
Centre for Research on Inner City Health
Keenan Research Centre in the
Li Ka Shing Knowledge Institute of
St. Michael's Hospital

Angie Chan BA, MPA
Policy Analysis
Centre for Research on Inner City Health
Keenan Research Centre in the
Li Ka Shing Knowledge Institute of
St. Michael's Hospital

Michael Gardam MSc, MD, CM, MSc, FRCPC
Pandemic Influenza & Policy Analysis

Director
Infectious Diseases Prevention and Control
Ontario Agency for Health Protection and Promotion

Medical Director
Infection and Prevention and Control
University Health Network

Staff Physician
Department of Medicine
Division of Infectious Diseases
University Health Network

Assistant Professor
Faculty of Medicine and
Dalla Lana School of Public Health
University of Toronto

Christine Heidebrecht BA, MSc
Project Coordinator
Centre for Research on Inner City Health
Keenan Research Centre in the
Li Ka Shing Knowledge Institute of
St. Michael's Hospital

Wei Hu BSc, BEng
Data Analysis
Centre for Research on Inner City Health
Keenan Research Centre in the
Li Ka Shing Knowledge Institute of
St. Michael's Hospital

David Andrew Janes BES (candidate)
Geography Student
University of Waterloo

Michael MacDonald BA, MSA
Geographic Information Systems (GIS)
Department of Geography
Ryerson University

Jennifer Sears BSc
Research Assistant
Centre for Research on Inner City Health
Keenan Research Centre in the
Li Ka Shing Knowledge Institute of
St. Michael's Hospital

Paulo Raposo BSc
Cartographer
Centre for Research on Inner City Health
Keenan Research Centre in the
Li Ka Shing Knowledge Institute of
St. Michael's Hospital

Susan Wang BSc (candidate)
Life Sciences Student
Queen's University

ACKNOWLEDGMENTS

We wish to thank the Public Health Agency of Canada for generously funding the scientific research to produce this report.

We also wish to thank the Emergency Management Unit of the Ontario Ministry of Health and Long Term Care for supporting the development of a technological platform that significantly aided the conduct of our research.

The authors of this report maintained full control over all scientific research performed during the course of this project. The views expressed herein do not necessarily represent those of the Public Health Agency of Canada or the Ontario Ministry of Health and Long Term Care.

DISCLAIMER

The authors of this report received data from a variety of public and private sources without representation or warranty as to their accuracy and/or suitability for any purpose. While the authors of this report took exceptional measures to ensure that all data were of the highest quality, we decline responsibility for errors, omissions, or deficiencies in data, as well as any damages that may arise from reliance thereon.

RESEARCH ORGANIZATION

The conduct of this research was based out of the Centre for Research on Inner City Health – part of the Keenan Research Centre in the Li Ka Shing Knowledge Institute of St. Michael's Hospital.

The Centre for Research on Inner City Health (CRICH) at St. Michael's Hospital in Toronto is Canada's only hospital-based research organization focused on the health consequences of urban life and social inequality. Across a range of health conditions and in spite of universal health care policies, lower income populations are at greatest risk for illness and experience the greatest unmet need for health care services.

CRICH generates scientific evidence and tools to address these health-care barriers and to design effective interventions aimed at reducing health disparities. Our research priorities include: health-promoting neighbourhoods, health effects of homelessness and under-housing; and evaluating health services for marginalized groups. Our health database program maintains one of Ontario's most extensive arrays of administrative datasets pertaining to health and social services and also to community infrastructure.

Genuinely transdisciplinary, CRICH scientific strengths include economics, ethics, geography and GIS mapping techniques, health services research, medicine, psychology, psychiatry and social epidemiology. One-third of CRICH faculty members are front-line physicians at St. Michael's Hospital, providing a direct link between population research and patient care. Most issues studied at CRICH span multiple policy sectors, and CRICH researchers are called upon to collaborate with communities and decision-makers in health care, housing, community and social services, urban planning and immigration portfolios.

ADDENDUM

The scheduled release of this report in April 2009 was temporarily delayed by the onset of the international influenza A H1N1 epidemic originating in Mexico. While the authors of this report are well aware of current conditions pertaining to influenza A H1N1, this report was finalized prior to the onset of this event and consequently does not include analyses specific to this epidemic.

LIST OF EXHIBITS

British Columbia

Quebec

Alberta

Atlantic Canada

Saskatchewan and Manitoba

Northern Canada

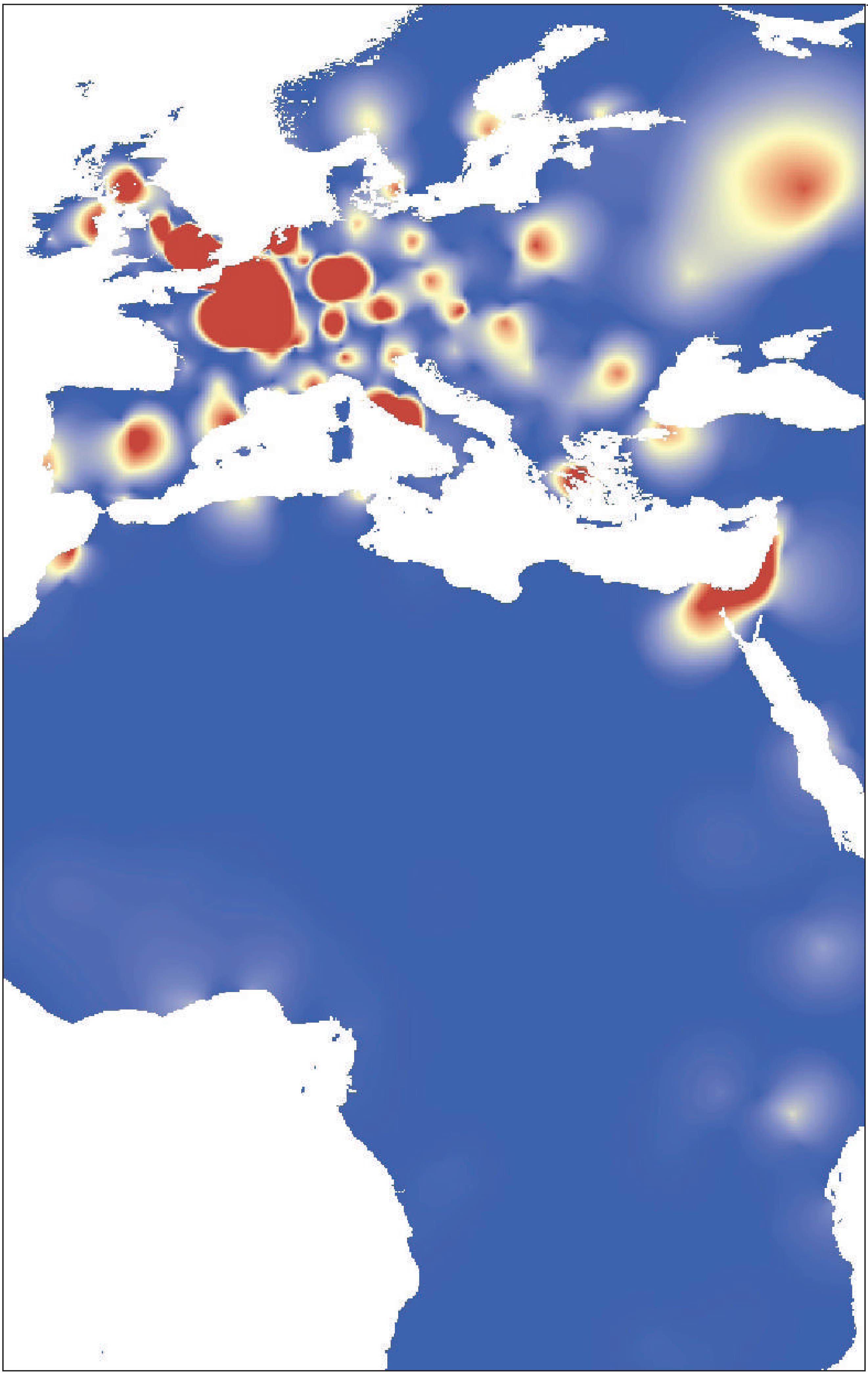
Disease Emergence & Control Indicators

Simulations

Outbound from Selected International Epicentres

Inbound to Canada from the International Community

EXECUTIVE SUMMARY



Infectious diseases have always crossed national boundaries; however, the speed at which an infectious agent can now disseminate around the world was exemplified by the SARS coronovirus in 2003. This previously unknown virus emerged in the Guangdong province of China and rapidly disseminated around the world via the global airline transportation network. Canada imported cases of SARS through airports in Vancouver and Toronto, leading to 44 deaths, industry losses in billions of dollars, and expenditures exceeding one billion dollars to control the outbreak in Ontario. This landmark event highlighted Canada's vulnerability to global infectious disease threats.

This report examines in unprecedented detail, the complex and evolving fabric of the global airline transportation network from the perspective of Canadian public health security. Using real data on the complete architecture of the global airline transportation network and the more than two billion passengers traveling through it each year, this report meticulously evaluates Canada's vulnerability to global infectious disease threats. Strategies to mitigate the risks of importation and their consequences are proposed at three frontiers moving from domestic to international:

1. Major domestic points of entry used by air travelers arriving in Canada
2. Major international transit points used by air travelers coming to Canada
3. Leading global sources of international air travelers coming to Canada

1. Reinforcing Lines of Defence at Major Domestic Points of Entry

Three cities – Toronto, Vancouver, and Montreal – receive more than eighty percent of all international air traffic flowing into Canada from the developing world. Thus, if global infectious disease threats are to breach Canada's borders by air, it is highly probable they will do so through one or more of these locations. By all metrics, Toronto is the most vulnerable domestic point of entry in Canada – ranking alongside the world's most centrally located cities within the global airline transportation network and receiving the international air traffic volumes of Vancouver and Montreal combined.

Although it is a smaller, less populated city than Montreal, there are several reasons why Vancouver appears to be the second most vulnerable point in Canada. First, by most metrics it is more centrally located within the global airline transportation network. Second, it receives a greater volume of international travelers from around the world than Montreal. And third, Vancouver is Canada's most strongly connected point to East Asia. East Asia is of special concern because it is where SARS originated, where human cases of highly pathogenic (H5N1) avian influenza are occurring in their greatest numbers, and where many experts fear pandemic influenza and other emerging infectious diseases may originate. Should future threats arise in East Asia, Vancouver would likely be Canada's most vulnerable domestic point. This prediction is consistent with observations during SARS, as Vancouver received more imported cases of this disease than any other city in Canada. While Montreal is a major metropolis, it is more sequestered in the global airline transportation network than either Toronto or Vancouver, with a substantial majority of its international traffic originating in Europe, North Africa, and the Middle East. These origins are felt to be of lower risk for the importation of emerging infectious diseases.

Taking into consideration the global connectivity of Canada's largest cities and the presumed international sources of future infectious disease threats, it would be prudent for Canada to strengthen its emergency preparedness and response capabilities in Toronto, Vancouver and Montreal, in this order of priority. At a minimum, Canada should consider designating its international airports at Toronto and Vancouver under the terms of the revised International Health Regulations, and strongly consider designating Montreal's international airport as well. While Calgary's status in the global airline transportation network is evolving, its current level of global connectivity via commercial air travel remains somewhat limited. Periodic reevaluations of Calgary and other Canadian cities will be needed to determine how their status evolves over time.

2. Reinforcing Lines of Defence at Major International Transit Points used by Travelers Coming to Canada

Of all international travelers arriving in Canada from the developing world, sixty percent use more than one flight to reach their final destination. Commercial airports outside of Canada where these flight connections occur represent a potential "upstream" frontier for intervention. Of note, half of all flight connections made by passengers traveling to Canada from developing areas of the world occur in the airports of just nine cities worldwide. These cities listed by order of frequency are: i) London, UK, ii) Hong Kong, iii) Tokyo, iv) Frankfurt, v) Paris, vi) Miami, vii) Amsterdam, viii) New York City, and ix) Chicago. In total, these nine cities account for 1.4 million flight connections directing passengers into Canada every year. Given the potential for travelers infected with dangerous pathogens to become ill during flights or flight layovers, it may be prudent to collaborate with these airports and their respective governments, in an effort to educate and/or screen travelers, particularly during the midst of epidemics of international significance.

3. Reinforcing Lines of Defence at Leading Global Sources of International Travelers to Canada

In order for global infectious disease threats to enter Canada's borders by air, a series of three connected steps must occur. First, an infectious agent of public health and/or economic significance must arise somewhere in the world; second, the infectious agent must gain access to the global airline transportation network; and third, air traffic flows departing the source location must direct the agent into a commercial airport inside Canada's borders. Consequently, the risk of importing global infectious disease threats into Canada is a composite of the probabilities for each step. Considering these factors, four developing and nine industrialized countries have been identified as important potential locations from which infectious disease threats may enter Canada's borders. Collectively, these thirteen countries generate eighty percent of all international traffic entering Canada from around the world.

Developing Economies

China, including Hong Kong, generates the third largest volume of international passenger traffic entering Canada after the United States and the United Kingdom. Of all international passengers entering Canada today, approximately one in twenty-five initiates their trip from within China's borders. Of these passengers, ninety percent depart from just three cities – Hong Kong, Beijing, and Shanghai. China is of particular interest from the perspective of infectious disease threats because of the country's historic association with diseases such as SARS and communicable agents of avian origin due to the high co-density of humans and birds. Furthermore, as a nation comprising extremes of poverty and wealth, conditions in certain areas of the country may foster the emergence of infectious diseases while others provide a platform for international dissemination via air travel. In the case of SARS, a synergy of conditions contributed to the international dissemination of this disease – with its initial emergence and propagation in Guangdong province coupled with the flows of air traffic generated by the fifth largest international airport in the world in neighbouring Hong Kong. Similar conditions and circumstances could contribute to the international dissemination of pandemic influenza of avian origin (e.g. H5N1) or other infectious disease threats that may emerge from within China's borders.

Mexico generates the second largest volume of international passenger traffic entering Canada from any developing country after China. A substantial majority of this traffic flows into Canada from resort cities like Cancun and Puerto Vallarta between January and April, largely representing Canadians returning home from winter and spring vacations. Throughout the year however, Mexico City continues to be a steady source of air traffic into Canada, producing almost 190,000 passengers annually. After Hong Kong, Mexico City is the largest urban source of air traffic into Canada from a developing country. Poverty, high population density, limited healthcare resources, coupled with a high volume of international inbound traffic to Canada provide conditions that could make Mexico City an important future source location.

India is a major developing country with high population density and focal areas of accelerated industrialization. The conditions of poverty and expanding wealth within India bear a striking resemblance to those found in mainland China. Today, approximately one in fifty international travelers entering Canada's borders originates their trip from within India. Of these passengers, eighty percent depart from three cities – Delhi, Mumbai, and Amritsar. As India continues to industrialize and its relationship with Canada evolves, its significance as a potential source country for emerging infectious diseases may rise in tandem.

The Philippines generates the fifth largest volume of international passenger traffic entering Canada from the developing world after China, Mexico, India, and Cuba. While Cuba produces a slightly higher volume of international traffic entering Canada than the Philippines, a substantial proportion of Cuba's traffic represents Canadian travelers returning home from winter and spring vacations between January and April. The Philippines is felt to be of greater significance to Canada, as conditions in the country may be more conducive to the emergence of new or dangerous infectious diseases and because the Philippines is tightly interconnected with other East Asian countries where human cases of highly pathogenic (H5N1) avian influenza are being reported in substantial numbers.

Industrialized Economies

The United States (U.S.) generates by far the largest volume of international air traffic entering Canada of any country in the world. Today, approximately one in every two international passengers entering Canada does so from the U.S. While the U.S. may be an unlikely source for the emergence of new or dangerous infectious disease threats, it alone generates over 13% of the world's international traffic volume and in turn represents a high risk destination in and of itself. Given the extensive population mixing between the two countries via commercial air travel and land border crossings, the U.S. should receive special consideration as an important potential location from which infectious disease threats may enter Canada. With 51% of Canada's international air traffic coming from the U.S. and 13% of the U.S.' international air traffic coming from Canada; there are compelling reasons for both countries to cooperate on preparing for and responding to future global infectious disease threats.

The European Union (E.U.) generates almost one-fifth of all international traffic entering Canada. Like the United States, the E.U. may be an unlikely source for the emergence of new or dangerous infectious disease threats, but it generates over 19% of the world's international traffic volume and consequently represents a high risk destination in and of itself. Of E.U. member states, more than 75% of all traffic entering Canada originates from the following five countries by order of volume: i) United Kingdom, ii) France, iii) Germany, iv) Italy and v) the Netherlands. As with the United States, there are compelling reasons for Canada to consider collaboration with the E.U. on addressing common risks of global infectious disease threats.

Japan, South Korea, and Taiwan represent three highly industrialized economies in East Asia that could become primary sources of emerging infectious diseases to Canada, but may be more important as secondary sources after importing diseases from other less developed countries in Asia. Collectively, these three industrialized economies generate 3.8% of Canada's total volume of inbound international air traffic.

The spread of human infectious diseases is as old as human migration itself. However, since the advent of commercial air travel and the subsequent transformation in global population mobility, the line separating domestic from international threats has become increasingly blurred. While reinforcing domestic lines of defence is an essential component of a national biodefence strategy, Canada should consider a more diversified portfolio of options involving collaboration with specific airports, cities, and countries around the world. If Canada wishes to play a more active role in delaying or even preventing the domestic entry of infectious disease threats altogether, greater emphasis on international source control will be required. This report provides the data and evidence needed to help direct Canadian preparedness and response efforts to specific domestic and international locations that are most likely to serve Canada's national self-interests, while concurrently benefiting other countries and strengthening the fabric of global public health security.

SETTING THE STAGE

The birth of commercial air travel in the mid-20th century triggered a fundamental transformation in the global mobility of humankind. Since then, the world has become increasingly interconnected by the global airline transportation network. Today, this worldwide system of commercial airports across nearly 3500 cities carries more than two billion passengers through 35,000 commercial aviation arteries each year. While global interconnectedness confers tremendous benefits to humankind, it concurrently fosters interdependence and vulnerability. From the perspective of public health security, the global airline transportation network has become an important conduit for the worldwide spread of infectious diseases[1-3].

Canadian vulnerabilities to global infectious disease threats were fully exposed during the worldwide outbreak of severe acute respiratory syndrome (SARS), when a novel coronavirus emerging in China's Guangdong province found its way to the fifth largest international airport in the world in neighbouring Hong Kong[4,5]. Shortly thereafter, this communicable and highly virulent disease unsuspectingly penetrated Canada's borders through international airports in Toronto and Vancouver[6]. With a local outbreak ensuing in Toronto[7,8], the health and economic repercussions of this event were unprecedented in Canadian history. Hundreds became infected with SARS leading to 44 deaths; tens of thousands required quarantine; industry losses were incurred in billions of dollars; and expenditures exceeding one billion dollars were required to control the outbreak[9]. Often referred to as a "pandemic dress rehearsal", SARS was an abrupt reminder that Canada remains vulnerable to global infectious disease threats, whether originating from naturally occurring phenomena, accidental laboratory breaches, or intentional release.

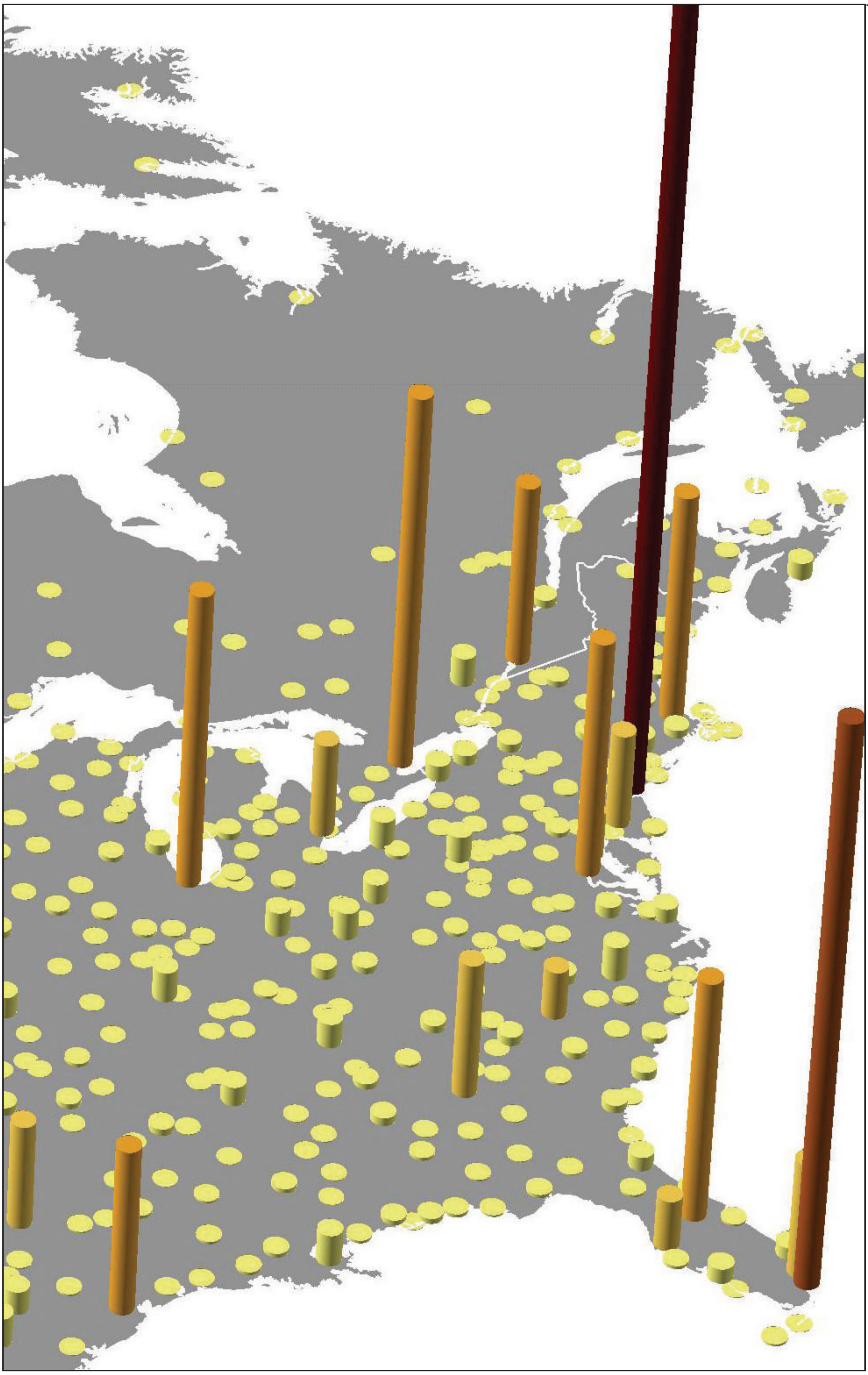
More recently, the global community has directed its attention to highly pathogenic (H5N1) avian influenza and its potential role in triggering the next influenza pandemic[10]. Even in the best case scenario, the global health and economic repercussions of an influenza pandemic would dramatically overshadow those felt during SARS[11]. Despite the expanding role of commercial air travel in the spread of emerging infectious diseases, a limited amount of research has been conducted to help countries better prepare for the realities of infectious disease threats in an increasingly globalized world[12]. For example, national or international pandemic influenza plans do not specifically account for global patterns of commercial air traffic and their implications for preparedness and response strategies[13,14]. Given that characteristics of the global airline transportation network appear to be correlated with the spatial dissemination patterns of infectious diseases[15-19], a rigorous assessment of how Canada's cities are interconnected with others around the world is warranted.

Notwithstanding the need for more applied research to meet the public health and security needs of nations and the international community at large[12], research on global population mobility has been stunted by limited access to quality data on the global airline transportation network and worldwide commercial air traffic patterns. As part of The BIO.DIASPORA Project[20], our multidisciplinary scientific team fulfilled this need by developing a data warehouse for the sole purpose of conducting methodological and applied research on commercial air travel and emerging infectious disease threats. This report embodies rigorous analysis of these data from multiple scientific perspectives – medicine, infectious diseases, public health, health policy, biostatistics, geographic sciences, network analysis, computer sciences, and mathematical modeling.

The primary objectives of this report are to shed light on: i) how Canada and its major regions and municipalities are connected with the international community via the global airline transportation network, and how this interconnectedness has evolved with time; ii) how Canada's global connectivity translates into domestic vulnerability to imported infectious disease threats; and iii) how Canada can best mitigate the risks and/or consequences of imported infectious disease threats through targeted preventive measures. Consistent with the philosophy of the revised International Health Regulations[21] to shift emphasis away from passive border control measures to a more proactive approach of containing infectious disease threats at their source, this report considers Canadian prevention strategies at three frontiers. These include: i) major domestic points of entry used by travelers arriving in Canada; ii) major international transit points used by air travelers coming to Canada; and iii) leading global sources of international air travelers coming to Canada. By focusing on each of the above frontiers Canada can strategically reinforce its domestic surveillance, control and response systems; strengthen public health security in commercial air travel; and develop global partnerships to address common threats – all key objectives of the revised International Health Regulations[21,22]. Consequently, Canada can directly serve its own national self-interests while concurrently benefiting other countries and strengthening the fabric of global public health security.

Prior to the advent of commercial air travel, local infectious disease epidemics lacked the ability to rapidly transform into global ones. Today, with more than two billion passengers flowing through the world's commercial aviation arteries every year, rapidly developing global outbreaks that were once considered impossible are now plausible and even probable. As Canada prepares itself for the inevitable infectious disease threats of tomorrow, it will benefit from a more sophisticated understanding of its continually evolving relationship with the world's cities via the global airline transportation network[23].

SCIENTIFIC METHODS



Conceptual Framework

At the onset of this project, a conceptual framework was developed to consider how the global airline transportation network may act as a conduit for the importation of dangerous infectious diseases into Canada. The framework contemplates a series of three interconnected frontiers, where Canadian efforts may be directed to minimize the likelihood of importation (see Exhibit 1).

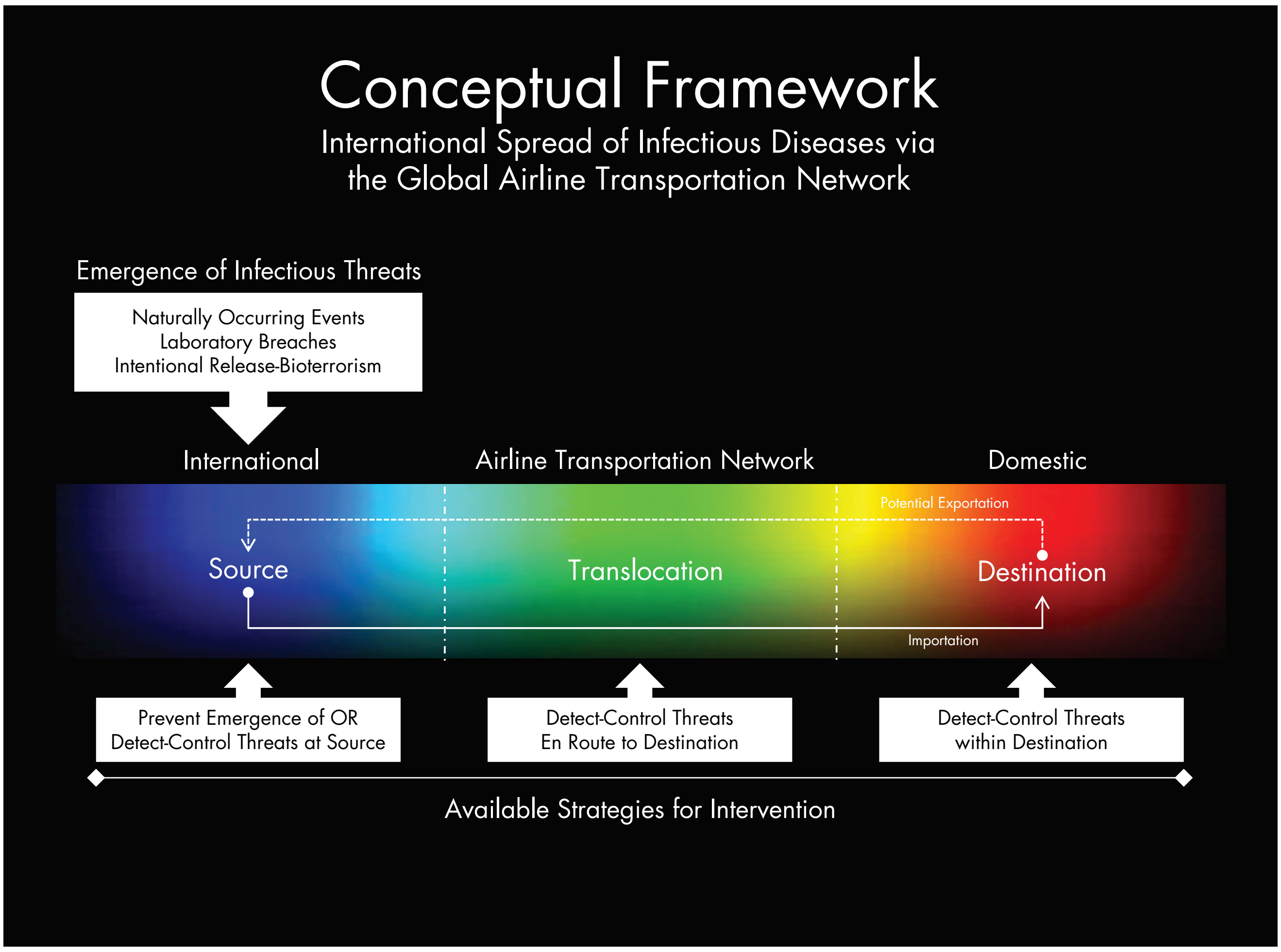
The first frontier considers the emergence of infectious disease threats from an international source. Threats may arise secondary to i) naturally occurring phenomena such as those driving the recurrence of influenza pandemics, ii) breaches at laboratories harbouring dangerous pathogens, and/or iii) the intentional release of infectious agents as acts of bioterrorism. The probability of achieving source control at this frontier is a composite of factors including, but not limited to i) characteristics of the infectious agent causing the threat and the setting in which it arises, ii) promptness with which the source location recognizes, identifies, and characterizes the threat, and iii) rapidity, intensity, and effectiveness with which the source location responds to the threat.

The second frontier considers the translocation of infectious agents via the global airline transportation network. In this report, only infectious agents that can be carried by passengers endogenously as latent infection or active disease or exogenously on articles of clothing or fomites are considered. While most endogenously transported agents cause human disease and consequently have implications to public health, exogenously transported agents may be the source of plant or animal infections that carry only economic consequences (e.g. hoof and mouth disease virus and the cattle industry). Infectious agents may be transported directly from source to destination via non-stop flights or indirectly via connecting airports. Opportunities to detect and respond to threats exist at airports where passengers embark, connect (if applicable), and/or disembark.

The third frontier considers the entry of infectious agents via commercial airports into their final domestic destination within Canada. The probability of preventing threats from entering the general population is dependent upon the point of entry's ability to i) quickly recognize, identify, and characterize the threat, and ii) rapidly and effectively respond to it. Should an infectious agent pass through the point of entry undetected, then its final domestic destination could potentially become a secondary source for disease exportation.

In public health terms, preparedness and response efforts directed at the international frontier are considered akin to primary prevention strategies since they aim to prevent the entry of infectious threats into Canada altogether. Efforts directed at the transportation network frontier are considered akin to secondary prevention strategies since they aim to detect and control threats en route to Canada – before they interact with the general population. Finally, efforts directed at the domestic frontier are considered akin to tertiary prevention strategies since they aim to minimize the health and/or economic consequences of infectious disease threats once they have already breached Canada's borders.

Exhibit 1:


Conceptual Framework
International Spread of Infectious Diseases via the Global Airline Transportation Network
Emergence of Infectious Threats
Naturally Occurring Events
Laboratory Breaches
Intentional Release-Bioterrorism
International
Airline Transportation Network
Domestic
Potential Exportation
Source
Translocation
Destination
Importation
Prevent Emergence of OR Detect-Control Threats at Source
Detect-Control Threats En Route to Destination
Detect-Control Threats within Destination
Available Strategies for Intervention

Data Contents

Data used to conduct the scientific research to produce this report are organized into two categories:

A. Commercial Air Travel: Includes information about the global airline transportation network and its role as a conduit for the international spread of infectious diseases. Data are global in scope but have been analyzed with emphasis on determining how Canada and its major regions and cities are interconnected with the international community. The primary sources of commercial air traffic data used in this report include:

- The Official Airline Guide (OAG)
- Airports Council International (ACI)
- International Civil Aviation Organization (ICAO)
- International Air Transport Association (IATA)

Worldwide OAG data from 2008 were used to study the architecture of the global airline transportation network, shedding light on how cities and countries around the world are interconnected. These data were also used to determine the types of flights entering cities (i.e. domestic or international or both) as well as the degrees of separation between cities, measured in flight connections needed to travel between a given city-pair. All measures of centrality (i.e. degree, betweeness, closeness) were also calculated using 2008 worldwide OAG data.

ACI data were analyzed across a period of ninety-six consecutive months between January 2000 and December 2007. This analysis facilitated the careful study of seasonal patterns and evolving long term trends in domestic and international passenger traffic across Canada's major municipalities. Due to the intrinsic nature of ACI data, all passenger flows are measured in arrivals plus departures.

ICAO data were analyzed across twenty-eight consecutive quarters between the beginning of 2000 and the end of 2006. This analysis was conducted to compare and contrast the flows of international passenger arrivals between the northern and southern hemispheres and different regions of the world. Furthermore, ICAO data were used to analyze the proportion of international traffic arriving into Canada's major municipalities from U.S. and non-U.S. points of origin over time.

Worldwide IATA data from 2007 were used to study passenger flows between city-pairs around the world. It bears noting that these flow data represent the true flight origins and destinations of passengers, as they take into account the specific routes and connection points (if applicable) used by travelers. IATA data were used for a number of purposes including:

i) Producing heat-maps that depict the flight origins of international passengers traveling into Canada

ii) Ascertaining the actual routes used by passengers traveling between cities around the world

iii) Conducting mathematical simulations of the worldwide spread of influenza

B. Global Conditions: The importation of infectious disease threats into Canada are a composite of three conditional probabilities: i) the probability of disease emergence at a given source location, ii) the probability that the source location detects and controls the threat before it accesses the global airline transportation network, and iii) the probability that international air traffic leaving the source location directs the threat into Canada's borders. Ten variables have been selected as surrogate markers for the emergence of infectious disease threats (with emphasis on pandemic influenza) and the ability of countries to detect and control infectious disease threats at their source. These data are presented to complement the commercial air traffic data in this report and to help readers better assess the overall risk of global infectious disease threats to Canada.

Variable 1: Global Human Population Density (in km^2 grids)
Data on global human population density were obtained from the Socioeconomic Data and Applications Centre (SEDAC) at Columbia University for the year 2005. Density values are presented worldwide in one square kilometre grids. This level of resolution addresses an important limitation of density data presented at the national level, which averages population values over densely and scarcely inhabited land areas.

Variable 2: Global Poultry Population Density (in km^2 grids)
Data on poultry populations worldwide were obtained from the Food and Agriculture Organization (FAO) of the United Nations for the year 2007. Concerns about avian influenza and its potential role in the emergence of a new pandemic strain of human influenza led to the inclusion of this variable. Poultry density is also presented worldwide in one square kilometre grids.

Variable 3: Global Human-Poultry Population Co-Density (in km^2 grids)
This co-density index was calculated as the product of human and poultry densities for each square kilometre grid worldwide. Areas with the highest co-density were considered optimal grounds for the interaction of avian and human influenza viruses and consequently for the emergence of pandemic influenza.

Variable 4: Highly Pathogenic (H5N1) Avian Influenza in Humans
Data on cases of highly pathogenic (H5N1) avian influenza in humans were obtained from the World Health Organization (WHO). Countries with the highest numbers of human cases were considered high risk areas for the emergence of pandemic influenza. The cumulative number of human cases between January 1st, 2003 and December 31st, 2008 are presented in a choropleth map.

Variable 5: Cities with Operation Laboratories Reported to Hold WHO Risk Group 4 Microorganisms
Data on the coordinates of laboratories reported to hold highly dangerous infectious pathogens were obtained from open sources. Although these laboratories tend to be highly secured, there are precedents of accidental breaches which could trigger international outbreaks. The locations of the world's known laboratories holding WHO Risk Group 4 microorganisms are presented as points on a world map.

Variable 6: National Economic Status
Data on Gross National Income per capita were obtained from the World Bank as

an index of poverty, with data reported by countries between the years 2000 and 2006. Countries with extensive poverty were those potentially facing conditions that could contribute to the emergence of dangerous infectious diseases (e.g. extensive crowding, inadequate sanitation infrastructure etc.)

Variable 7: National Health Expenditures per Capita
Data on national health expenditures per capita were obtained from the World Bank for the year 2005. Countries with limited healthcare resources were considered those potentially facing difficulties rapidly detecting and characterizing emerging infectious disease threats.

Variable 8: National Physician Density
Data on the number of physicians per capita were obtained from the World Bank and the World Health Organization. Given the wide time frame in which data were reported, national values are presented in a choropleth map with three colour ramps. Each ramp represents a specific time period with the greatest degree of confidence in the most current data (i.e. blue ramp; 2005-2008) and the weakest degree of confidence in the most outdated data (i.e. green ramp; 1990-2000). Countries with few physicians per capita were considered likely to face challenges detecting and responding to emerging infectious disease threats.

Variable 9: National Nurse Density
Data on the number of nurses per capita were obtained from the World Bank for the years 2000-2004. Countries with few nurses per capita were considered likely to face challenges detecting and responding to emerging infectious disease threats.

Variable 10: National Hospital Bed Density
Data on the number of hospital beds per capita were obtained from the World Bank and the World Health Organization. Given the wide time frame in which data were reported, national values are presented in a choropleth map with two colour ramps. Each ramp represents a specific time period with the greatest degree of confidence in the most current data (i.e. blue ramp; 2005-2007) and the weakest degree of confidence in the most outdated data (i.e. green ramp; 2000-2004). Countries with few hospital beds per capita were considered likely to face challenges responding to emerging infectious disease threats requiring hospitalization.

Data Quality

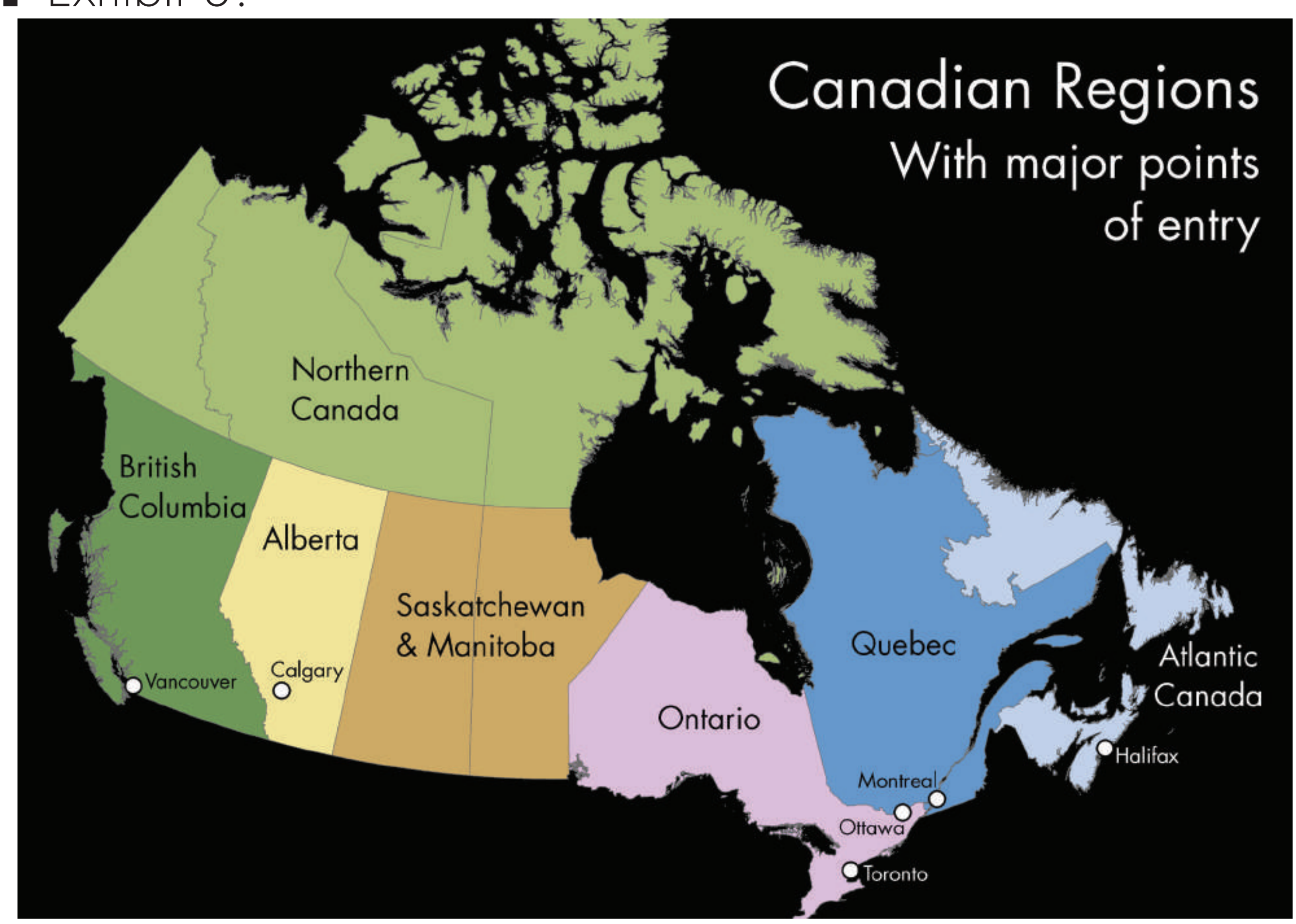
The commercial air traffic data used to produce this report were obtained from major international organizations, each of which has procedures in place to ensure data quality. However, our scientific team developed a set of secondary procedures to ensure that all commercial air traffic data were rigorously assessed before any analysis was initiated. The steps involved in this data quality check are described below:

First, all three-letter IATA airport codes from each of the four commercial air traffic datasets (i.e. OAG, ACI, ICAO, IATA) were matched and compared to verify that each code represented a unique commercial airport. Subsequently, a city masterfile was created that aggregated airport data for cities with more than one commercial airport.

For all variables with continuous values, a series of descriptive statistical analyses were performed to identify missing data elements and to detect the presence of outliers. Subsequently, the flows of air traffic in cities were plotted across time to facilitate a visual assessment of patterns and consequently identify unexpected deviations. Finally, autoregressive time series models were developed to generate best-fits with observed city-level flows of air traffic. Residuals from these models were then plotted, with explanations sought for large discrepancies (i.e. where observed values exceeded two standard deviations from expected values). Where unexplained discrepancies existed, queries were made back to the original source.

Exhibit 2:

Exhibit 3:



Data Analysis

Geographic Units

Cities represent the primary unit of analysis in this report. In most instances airport level and city level analyses are synonymous, with the exception of cities with multiple commercial airports. For such cities, data from each commercial airport were aggregated into a single unit, representing their collective characteristics.

For global sub-group analysis, the world was divided into ten distinct regions as indicated below and shown in Exhibit 2. The list of countries included in each world region was adapted from definitions used by the United Nations. The regions include:

i) Northern America
ii) Mexico, Central America and Caribbean Islands
iii) South America
iv) Western, Northern, and Southern Europe
v) North Africa and Western Asia
vi) Sub-Saharan Africa
vii) Eastern Europe and Central Asia
viii) East Asia
ix) Southern Asia
x) Australia, New Zealand, and Pacific Islands

Certain sub-group analyses were performed that distinguished developing from industrialized regions of the world. The developing world was defined by excluding i) Northern America, ii) Western, Northern, and Southern Europe, and iii) Australia, New Zealand and Pacific Islands from the ten regions listed above. Furthermore, a number of analyses considered the global airline transportation network from the perspective of a borderless European Union (E.U.). At the time of this analysis, the E.U. comprised twenty-seven member states including: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

For Canadian sub-group analysis, Canada was divided into seven distinct regions as indicated below and shown in Exhibit 3. Additionally, six major Canadian municipalities were selected for sub-group analysis as they represent the locations of the country's quarantine stations: The seven regions include:

i) Ontario (including Toronto and Ottawa)
ii) British Columbia (including Vancouver)
iii) Quebec (including Montreal)
iv) Alberta (including Calgary)
v) Atlantic Canada (including Halifax)
vi) Saskatchewan and Manitoba
vii) Northern Canada

With ten world regions, seven Canadian regions, and six Canadian municipalities, 130 potential sub-group analyses are possible. In this report, the intersection of global and Canadian regions is examined as deemed necessary.

Statistical Analysis

Descriptive statistics were used to analyze passenger flow volumes, identify the routes and transit points used most frequently by passengers en route to Canada from around the world, and examine trends in passenger traffic over time. All statistical analyses were conducted using SAS version 9.1.

Network Analysis

The architecture of the global airline transportation network was analyzed using network analysis. All analyses were performed using 2008 data from the Official Airline Guide (OAG). In 2008, there were a total of 3,445 cities with commercial airports in operation worldwide. All network analyses were performed using this number of cities.

Examining the airline transportation network from a global perspective, a connectivity matrix was produced to visually depict the world's commercial aviation arteries. The connectivity matrix comprises two axes, along each of which 3,445 cities (with at least one operational commercial airport) are represented. Each of the 35,122 dots on the matrix represents the existence of an artery directly connecting a city-pair (i.e. arteries represent non-stop flight routes connecting city-pairs). For definition purposes, non-stop flights are considered those where the aircraft does not land anywhere between the departure city and the destination city. By comparison, direct flights are considered those where the aircraft does land somewhere en route to the final destination city. At this location, new or onboard passengers may or may not be permitted to embark or disembark the aircraft respectively. Throughout this report, cities are considered "directly" connected only if there is a non-stop flight between them.

Cities within Canada were evaluated to identify the types of flights that they are capable of receiving. For Canadian cities, the categories included those receiving: i) domestic flights only, ii) U.S. international flights (in addition to domestic flights), and iii) non-U.S. international flights (in addition to U.S. international flights and domestic flights). The use of the word "international" in airport names was not considered as some airports do not currently accept international flights but have in the past and have kept the term "international" in their name. Conversely, other airports do not use the term "international" but clearly receive international flights.

Analyses measuring degrees of separation between world regions and Canadian regions and/or municipalities are also included. In network theory, directly connected nodes generally have greater potential for flow relative to nodes that are not directly connected. With increasing steps between nodes, the potential for flow diminishes. In the context of infectious disease threats, this implies that cities connected through non-stop flights are most vulnerable to the exchange of infectious diseases between them, with risks of spread decreasing with increasing steps.

Network analysis was also used to generate three established measures of centrality – in-degree, betweeness, and closeness. In the case of this report, in-degree centrality communicates vulnerability to infectious disease threats since it identifies the number of non-stop pathways into a city from elsewhere in the airline transportation network. Conversely, out-degree centrality communicates the potential risk that a city will export an infectious disease threat. For the purposes of this analysis, only in-degree centrality is reported.

To assist with interpretation, total or "global" in-degree centrality values for Canadian cities are divided into three categories: i) domestic, ii) U.S., and iii) non-U.S. international. The values for each category represent the number of non-stop connections into a given city from domestic, U.S., and non-U.S. international points of origin. This analytic approach enables readers to evaluate both the number and type of inbound pathways into Canadian cities.

International in-degree values for many European cities are somewhat artificially inflated, given that flights between different countries of the European Union (E.U.) are defined as international, even though the E.U. is, for all practical purposes, a borderless entity. For specific analyses of international in-degree centrality, the E.U. has been defined as borderless, providing a more reasonable assessment of the significance of European and non-European cities worldwide.

Betweeness centrality is a measure of how frequently a city lies along the shortest path between other city-pairs throughout the global airline transportation network. Cities with high betweeness have the potential to be important locations where diseases pass through since travelers generally prefer to take the shortest route to their final destination. Heightening infectious disease surveillance in the airports of cities with high betweeness may be a strategy to consider if intercepting the movements of infectious agents within the global airline transportation network is under consideration. In networks, nodes with high betweeness tend to be very important with respect to their ability to facilitate or restrict flows. In this analysis, betweeness values for all cities were normalized between zero (lowest betweeness) and one (highest betweeness).

It bears noting that cities' betweeness centrality is a "structural" metric that reflects their potential as a conduit for passengers to travel through while en route to their final destination. Under real-world circumstances, passengers for a variety of reasons may not actually use the shortest paths available. In a separate set of analyses, cities with the highest betweeness centrality values worldwide and cities that are passed through most often as transit points worldwide are compared.

Closeness centrality is a measure of how accessible a given city is to all other cities in the global airline transportation network. For this analysis, closeness has been calculated taking into account the travel time for each passenger seat to move between every city-pair worldwide. To calculate the travel time for passenger seats, closeness values were weighted by aircraft size (i.e. the number of passenger seats for each type of aircraft) and the traveling speed of those aircraft measured as median flight times between city-pairs. In the context of infectious disease threats, cities with high closeness centrality are at greater potential risk of importing infectious disease threats than cities with lower closeness centrality values. As with betweeness, closeness values were normalized between zero (lowest closeness) and one (highest closeness). All network analyses were performed using Pajek version 1.23.

Mathematical analysis

i. Overview

A mathematical framework was employed to integrate the science of infectious diseases with network analysis and transportation geography. Through this convergence of scientific disciplines, the spread of diseases within and between the world's cities is examined. Simulations are used to determine if and how diseases are likely to penetrate Canada's borders through commercial air travel.

Given present day concerns about highly pathogenic (H5N1) avian influenza and its potential role in triggering the next influenza pandemic, simulations throughout this report have been developed based upon the biological characteristics of the (seasonal) influenza virus. All simulations have been conducted using 2007 worldwide passenger traffic data. These data reflect the actual movements of passengers throughout the global airline transportation network, by accounting for connecting flights and the actual flight paths used by passengers. The infectious "seed" used to initiate each simulation entails the introduction of two infectious and ten exposed individuals at each hypothetical disease epicentre. For each simulation it is assumed that there are no effective measures in place to prohibit infectious persons from traveling via commercial aircraft.

Two types of simulations are performed. First, outbound simulations are those in which a single city is selected as a hypothetical disease epicentre and the outward spread of disease is subsequently observed. Inbound simulations are those in which 596 global cities outside of i) Canada, ii) the United States, and iii) Western, Northern, and Southern Europe (i.e. cities with the highest international air traffic volumes) are selected as hypothetical disease epicentres and the outward spread of disease is subsequently observed from each city. An analysis is then performed to determine which epicentres most frequently result in the exportation of disease into Canada. While outbound simulations evaluate threats based on specific "what if" scenarios, inbound simulations identify which cities in the world would pose the greatest risk to Canada if they were the source of an infectious disease threat. To illustrate how importation risks to Canada vary across seasons, inbound simulations are conducted for each quarter of the year.

ii. Dynamical Systems

Dynamical systems are distinguished as either deterministic or stochastic. Deterministic systems are ones which exhibit identical behaviour when analyzed repeatedly using the same initial set of conditions and parameter values. Conversely, stochastic systems involve randomness and consequently exhibit variable behaviour when analyzed using the same set of initial conditions and parameter values. As such, deterministic systems provide insights into average behaviour, while stochastic systems consider the distribution of possible realizations stemming from a single event. Given the intrinsic randomness with which infectious diseases spread from person to person and city to city, stochastic simulations have been used throughout this report. To evaluate the effects of stochasticity, 5000 simulations were performed for all outbound analyses. For inbound analyses, 2000 simulations were performed for each of the 596 hypothetical disease epicentres considered.

iii. Spread of Infectious Diseases between Cities

A metapopulation framework was used to simulate the spread of infectious diseases between cities around the world. Conceptually, metapopulations represent a network of populations that are interconnected with one another. The theoretical framework for this interconnectivity is rooted in graph theory, where each network node (i.e. population) is part of a multi-digraph (i.e. a directed graph in which the arcs joining nodes are oriented in a specific direction). An important limitation of the kind of metapopulation framework used in this report is that it assumes homogeneous mixing of individuals and consequently infectious diseases within cities.

iv. Spread of Infectious Diseases within Cities

An SEIR model was developed to simulate the person-to-person spread of infectious diseases within the world's cities. SEIR models consider individuals in one of four epidemiologic classes: i) **S**usceptible, ii) **E**xposed, iii) **I**nfectious, and iv) **R**emoved. Susceptible individuals may become exposed and infected during contact with an infectious person. Thereafter, infected individuals remain asymptomatic during the infectious agent's incubation period (i.e. the time between exposure and the development of illness). Subsequently, individuals may become infectious. After remaining infectious for a period of time, individuals may then either recover with immunity or die and thus are removed from the infectious class.

To simplify the SEIR model, a number of assumptions are made:

1. The total population of a given city is assumed to be effectively equivalent to the number of susceptible individuals in the population. This is because the model focuses on newly emerging infectious diseases for which it is assumed that individuals lack intrinsic immunity.
2. The number of removed individuals is negligible over the short (i.e. twenty-one day) time horizon used for simulations.

These two assumptions mathematically simplify the model to focus on two epidemiological classes – exposed and infectious. The (stochastic) EI model used in this report is a continuous-time, discrete-space Markov chain. A general overview of the model is described below.

1. The system at time t_0 is in the state $X(t_0)$. This state indicates the number of exposed and infectious individuals at time t_0 for every city throughout the global airline transportation network.
2. Based on the state $X(t_0)$, the time at which the system makes a transition is determined. This time is a random quantity determined by a random variable with an exponential distribution.
3. When a transition occurs, the nature of the transition is determined. Potential transition possibilities include the following:

(a) In a city with infectious individuals, an uninfected individual may become exposed leading to the development of a new (latent) infection.

(b) In a city with exposed individuals, an exposed individual may become infectious.

(c) In a city with infectious individuals, an infectious individual is removed from the infectious population due to recovery with immunity or death.

(d) An exposed individual in city a travels to city b.

(e) An infectious individual in city a travels to city b.

The relative probabilities of these outcomes are determined using information about the biological characteristics of the infectious agent of interest (i.e. seasonal influenza in this report) and worldwide passenger traffic flows via the global airline transportation network.

4. The process repeats itself from step 1.

All mathematical analyses were conducted using MATLAB version 7.7. Detailed information about the mathematical models used in this analysis is presented in the Technical Appendix.

Cartography

All maps were carefully designed with respect to colour and drawing elements for optimal viewing on flat-screen liquid crystal display (LCD) or cathode-ray tube (CRT) monitors. Maps are well suited for colour printing but are not designed for black and white printing or photocopying. To provide readers with the fullest geographic detail possible while maintaining sound cartographic design, a number of maps have been hyperlinked to a GIS server. Maps available for viewing via the server utilize scale based rendering, which provide readers with added layers of geographic detail as they are needed. Readers may also freely interact with the maps and their data elements via the GIS server. All cartographic work in this report was conducted using Environmental Systems Research Institute, Inc. (ESRI) ArcGIS 9.3 software.

Several different types of maps are presented throughout this report, each of which varies in its depictive purpose. These maps are described below to assist with cartographic interpretation.

Maps presented in this report generally fall into one of four varieties:

i) Network Architecture
ii) Passenger Flows
iii) Disease Emergence & Control Indicators
iv) Simulations

Network Architecture maps are designed to illustrate structural features of the global airline transportation network. Examples of architecture maps include those demonstrating Canadian and U.S. cities by the origin of flights received and the number of flight connections required to enter a particular region in Canada from around the world.

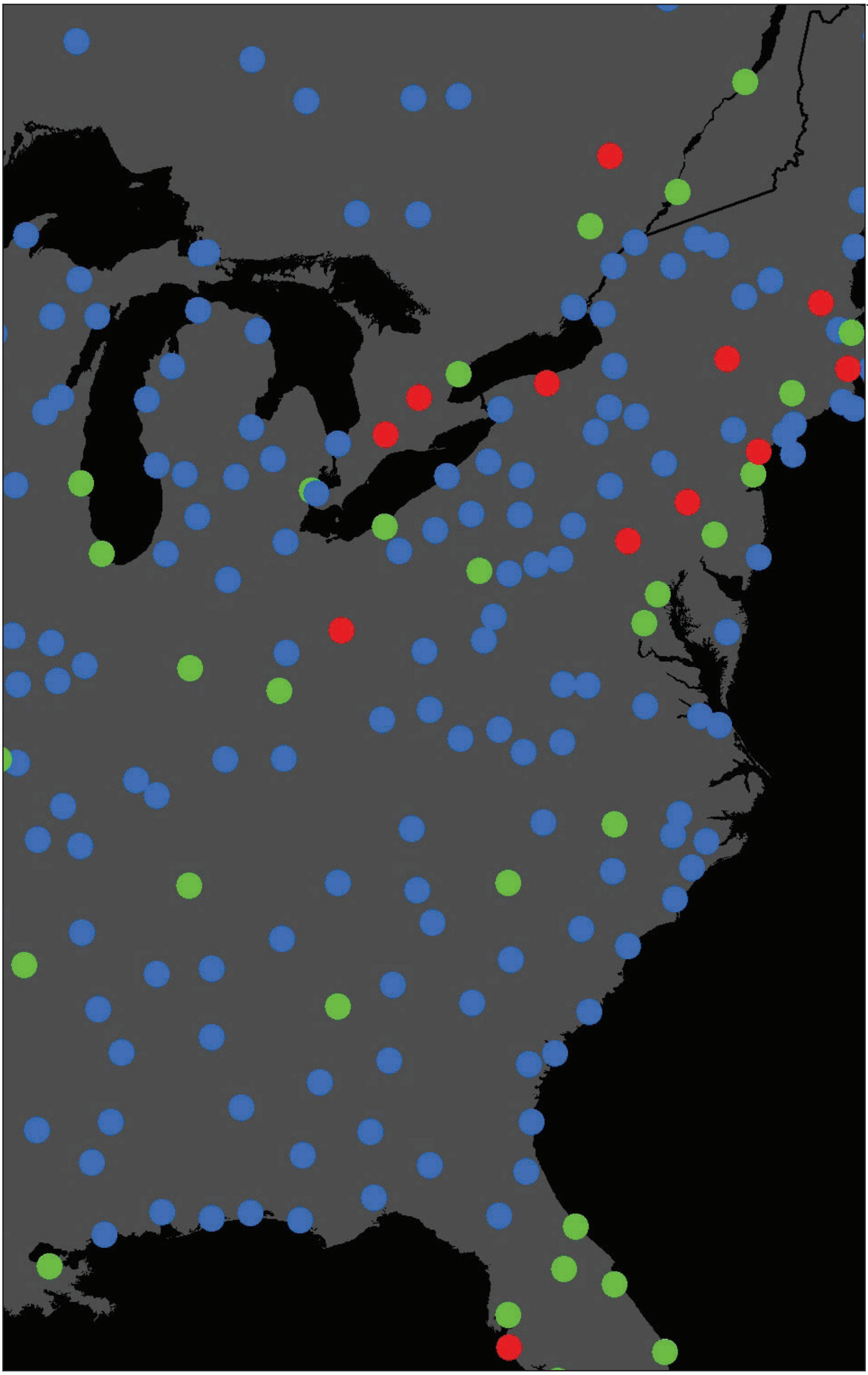
Passenger Flow maps are predominantly presented as heat-maps (i.e. they use colour differences to depict variance in flow volumes). These maps are designed to describe spatially discrete quantitative differences through space in a narrative visualization that treats them as continuous, wave-like spatial fluctuations. It should be stressed that these maps are not strictly speaking, spatially precise. Rather, they are abstract visualizations designed to direct the eyes of readers to cities in the world where passengers are initiating trips to Canada in their greatest numbers. The presence of a “hot-spot” illustrating high passenger volume at a particular city may extend some distance beyond the city’s borders and potentially coalesce with other “hot-spots” from neighbouring cities. Readers should also be aware that colours depicting passenger volumes are shown on land masses only. Consequently, small islands or cities directly adjacent to major bodies of water may have smaller “hot-spots” than cities surrounded by larger areas of land.

When interpreting heat-maps, readers should initially inspect the Volume of Passenger Arrivals bar to assess the maximum flow of passengers represented by the map’s “hottest” areas. Each heat-map is unique in this regard, depicting relative flows of passengers. Consequently, different heat-maps should not be compared directly to one another, but rather interpreted independently.

Disease Emergence & Control Indicator maps have been produced to describe area-level factors such as the magnitude of human cases of avian influenza, a country's overall economic status, or the quantity of health and human resources available. Most are produced as choropleth maps, using solid colour differences to depict differences in values at a national level. Others however, such as those depicting human or poultry populations, use varying colour saturations throughout pixels of spatially-gridded data to visualize differences in density in square kilometre units.

Simulation maps use graduated symbols to illustrate the probability of infectious disease importation to a given city. Two types of simulation maps are shown – i) outbound simulations use orange graduated symbols, while ii) inbound simulations use red graduated symbols. A description of each type of simulations is provided in the Mathematical Analysis section of the Scientific Methods.

RESEARCH FINDINGS



GLOBAL PERSPECTIVES

The global airline transportation network has a complex architecture, but one that is amenable to rigorous study. Today, there are more than 3,400 cities worldwide with commercial airports in operation carrying 2.1 billion passengers annually. During these trips, more than eight hundred million people fly across national boundaries and consequently present opportunities for the international spread of infectious diseases. Herein, architectural features and passenger flow dynamics of the global airline transportation network are presented.

Exhibit 4 presents a visual depiction of the global airline transportation network's architecture in 2008. The image illustrates the interconnected nature of cities worldwide in a matrix. Along each axis (i.e. origin and destination) are the 3,445 cities worldwide with at least one operational commercial airport. For simplicity, each axis is shown with the ten world regions described previously, with Northern America separated into Canada and the United States. Each dot on the matrix represents the existence of an artery directly connecting a city-pair (i.e. arteries represent non-stop flight routes connecting city-pairs). This figure allows readers to broadly view the intensity of interconnectedness within or between world regions.

It is readily visible and perhaps not surprising to see that there is much greater intraregional connectivity than interregional connectivity in the world. For example, Canadian cities are most tightly interconnected with others in Canada, followed by cities in i) the United States, ii) Mexico, Central America and the Caribbean, and iii) Western, Northern, and Southern Europe. On the opposite end of the spectrum, Canadian cities have no non-stop connections with cities in i) Australia, New Zealand and the Pacific Islands, and ii) Sub-Saharan Africa.

Measures of network centrality are important indicators of where nodes are positioned within a network and consequently speak to their significance as recipients or facilitators of flows through the network. In the case of the global airline transportation network, the centrality of cities describes their vulnerability to the importation and/or translocation of infectious diseases. Three metrics of centrality (i.e. in-degree, betweeness, and closeness) and their global rankings are presented for cities with at least one commercial airport worldwide.

Exhibit 5 illustrates international in-degree centrality values and global rankings for the most central cities worldwide in addition to six major cities within Canada. This measure of centrality quantifies the number of non-stop pathways into a given city from international points of origin. Cities with higher values have a greater number of international pathways through which passengers and consequently infectious diseases may arrive.

This Exhibit demonstrates that there are 362 non-stop pathways into the city of London, England from around the world, making it the most central location worldwide (using international in-degree as a measure of centrality). Among Canadian cities, Toronto is the most central with 133 non-stop pathways entering it from international points of origin, placing it 17th among all cities worldwide.

Exhibit 4:

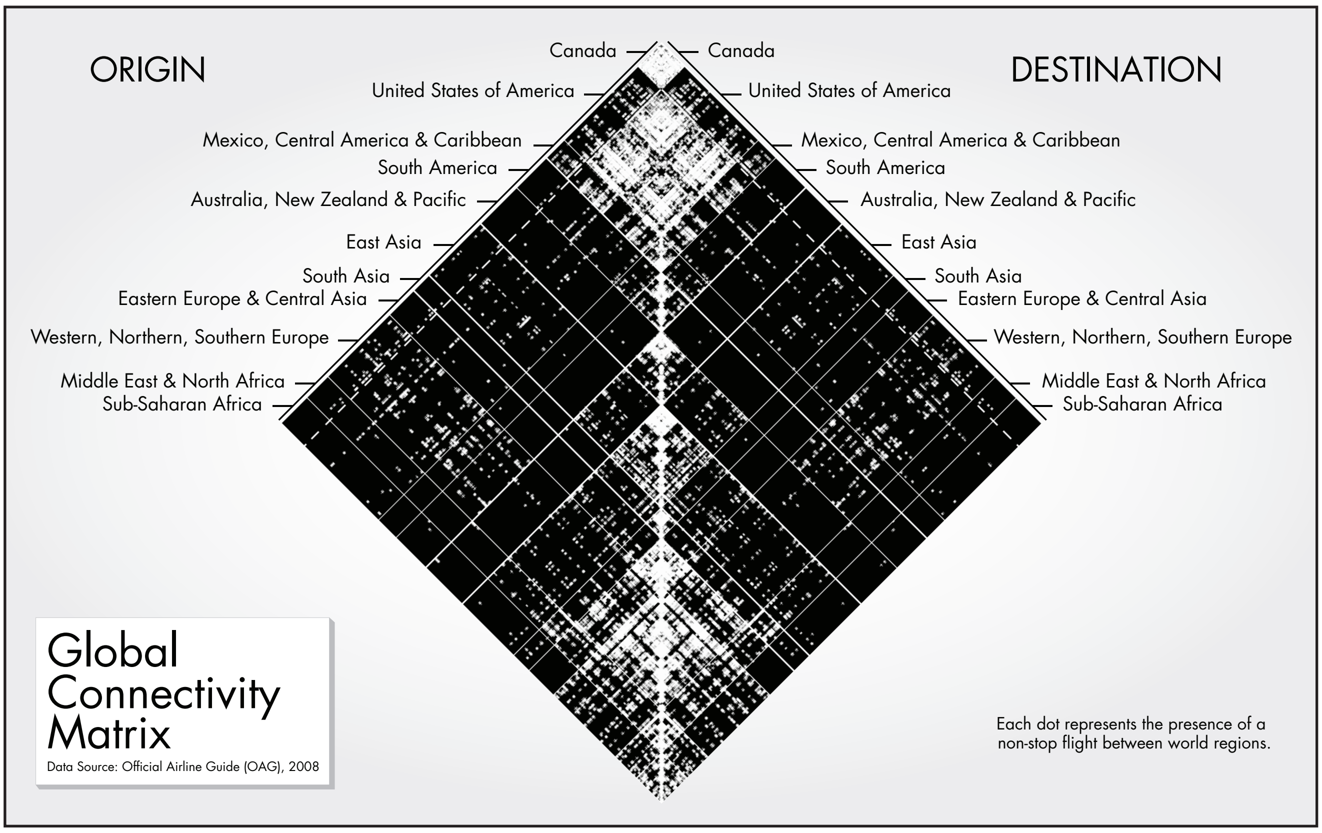
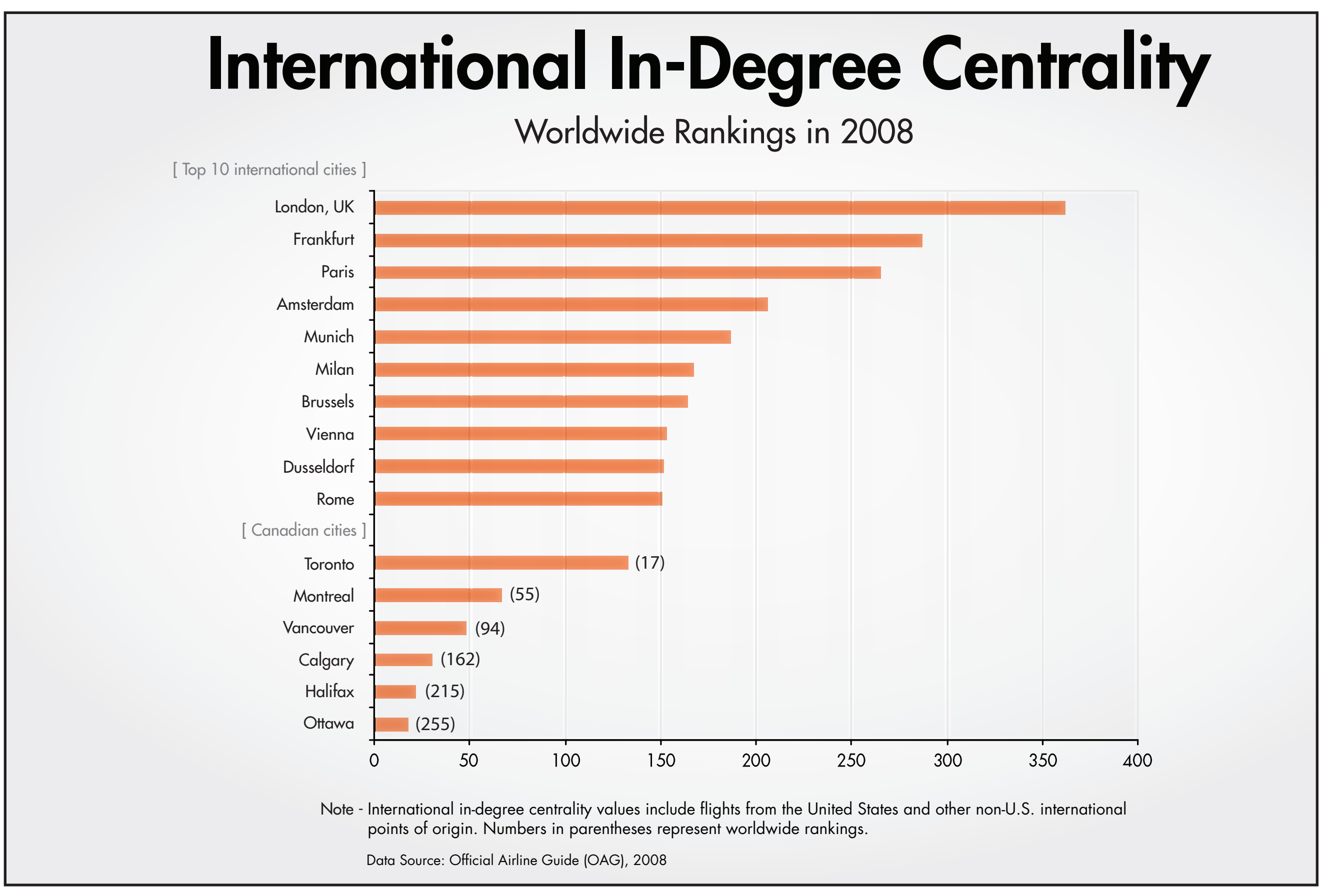


Exhibit 5:



Of note, the top ten most central cities worldwide (when using international in-degree centrality) are all European, in part because flights between countries of the European Union (E.U.) are defined as international. Given that the E.U. is effectively borderless, a separate analysis is presented in Exhibit 6, where flights between E.U. member states are considered domestic. This analysis provides a more realistic representation of international travel within Europe and provides a more reasonable comparison between European and non-European cities around the world. In this analysis, several non-European cities rise in significance, including Toronto which becomes the 8th most central location worldwide just behind Dubai and New York City and just ahead of Seoul and Istanbul.

Another important metric of network centrality is betweeness. In the case of the global airline transportation network, betweeness is a measure of how frequently a city falls along the shortest path between other cities throughout the network. This is an important metric because it highlights the potential for cities to act as conduits for the international spread of infectious diseases, since cities with high betweeness tend to be important transit points for passengers (and consequently infectious diseases) en route to their final destination. As such, these cities may be important frontiers to intercept and disrupt the international spread of infectious diseases through heightened surveillance, enhanced diagnostics for dangerous pathogens, concentrated health and human resources, or other interventions.

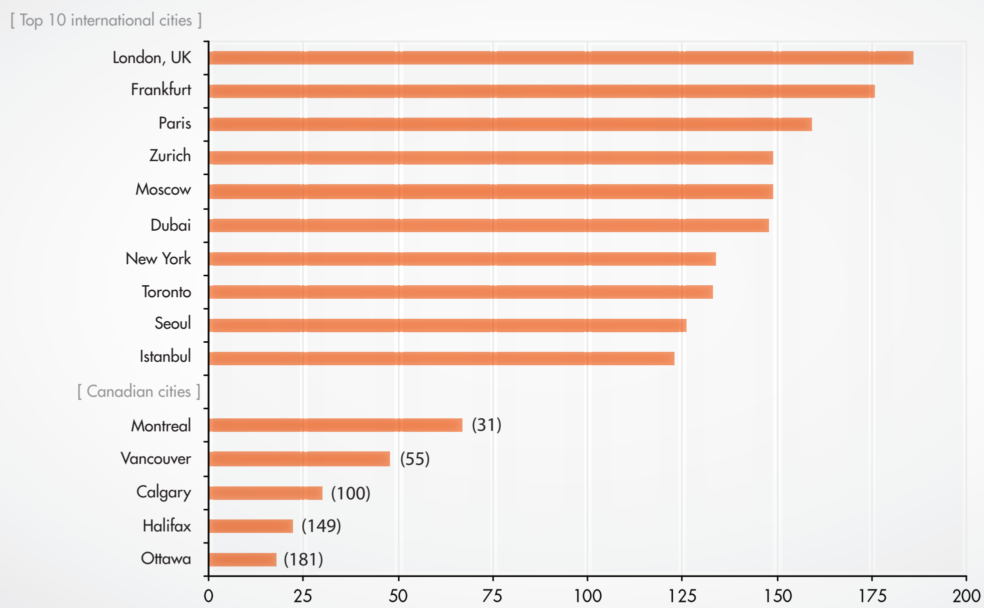
Exhibit 7 illustrates betweeness centrality values and global rankings for the most central cities worldwide in addition to six major cities within Canada. Values have been normalized between zero (lowest betweeness) and one (highest betweeness) to aid interpretation. Applying this metric, Frankfurt is the most central location in the global airline transportation network, followed closely by London, England. Of note, Anchorage, Alaska has the third highest betweeness value worldwide because it falls along the shortest path between many cities in North America and Asia. Other cities with high betweeness include Paris, New York City, Moscow, Tokyo, Los Angeles, Atlanta, and Sydney, Australia. Among Canadian cities, Toronto ranks 12th worldwide followed by Vancouver (18th) and Montreal (24th).

Centrality metrics in this report are based upon the architecture of the global airline transportation network, and consequently represent the potential for flow through the network. While it is implied that cities with high betweeness are important transit points for international passengers (i.e. places where flight connections are made), this may not actually be the case. Exhibit 8 identifies the cities worldwide that are most frequently used as transit points by passengers making international trips. When interpreted collectively, these exhibits demonstrate consistency between the potential for and the actual flows of passengers through the global airline transportation network. An apparent discrepancy is seen with Anchorage, Alaska which has a very high betweeness value and is likely a very important transit point for passengers passing between North America and Asia, but does not generate the exceptionally high volumes of transit passengers seen with other major global cities. Of the leading cities with the highest betweeness values worldwide,

Exhibit 6:

International In-Degree Centrality

Worldwide Rankings in 2008 (Borderless European Union)



International in-degree centrality values include flights from the United States and other non-U.S. international points of origin. Numbers in parentheses represent worldwide rankings.

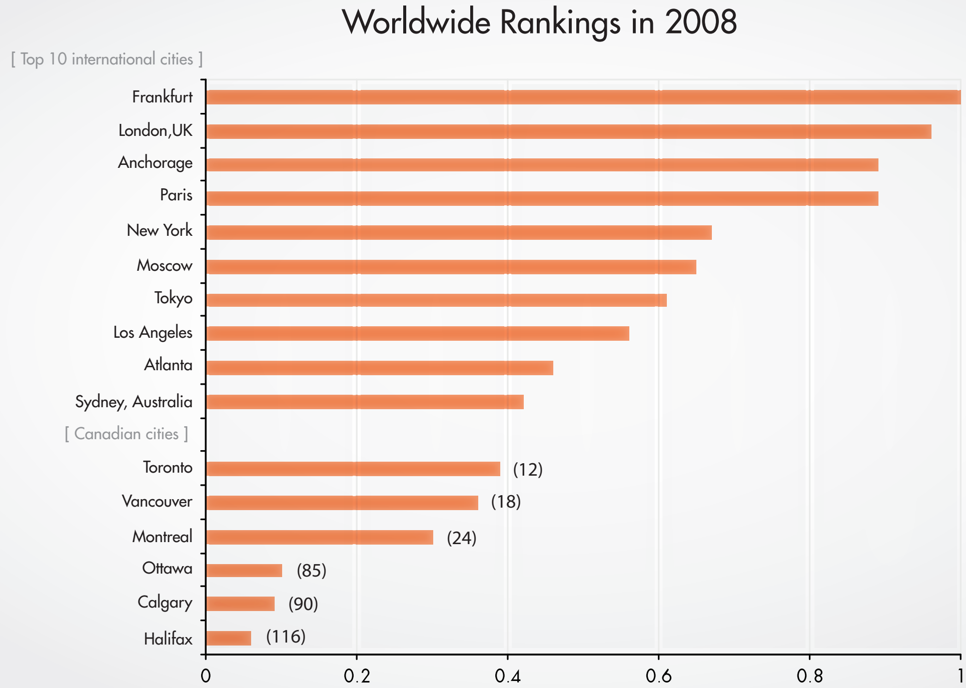
In this analysis, flights within the European Union are considered domestic movements.

Data Source: Official Airline Guide (OAG), 2008

Exhibit 7:

Global Betweeness Centrality

Worldwide Rankings in 2008



Values have been standardized to Frankfurt, the city with the highest betweeness score worldwide. Numbers in parentheses represent worldwide rankings.

Data Source: Official Airline Guide (OAG), 2008

Exhibit 8:

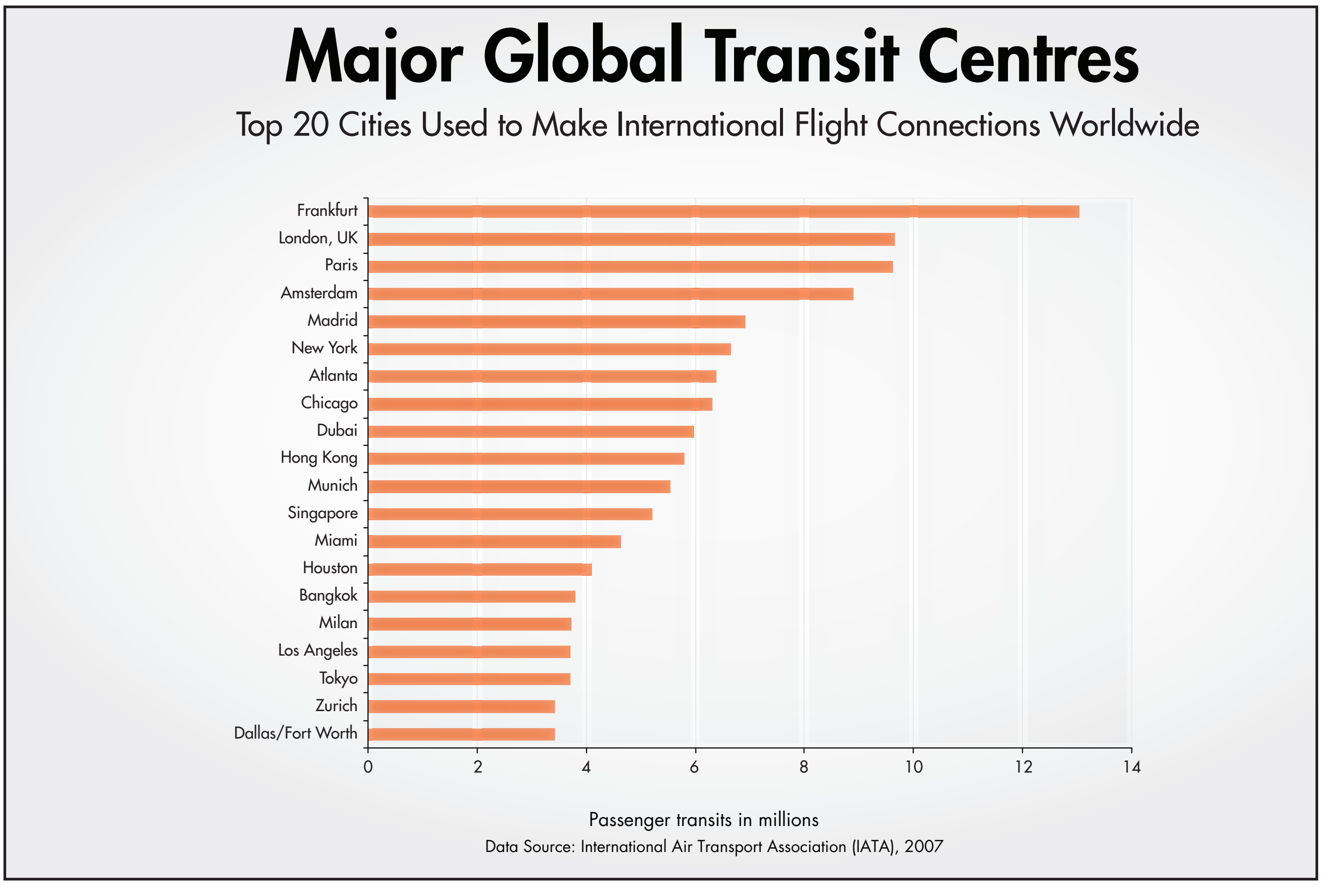
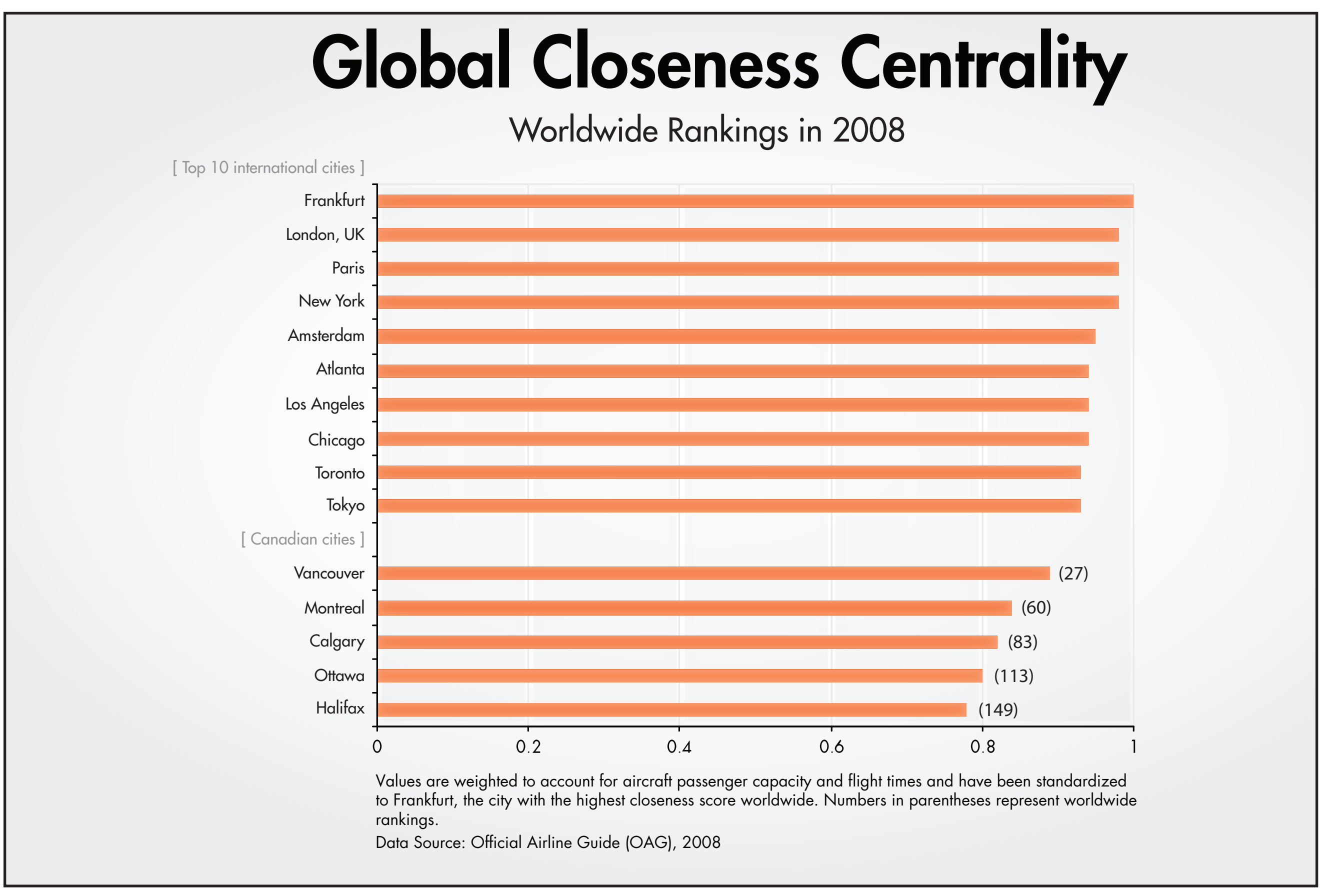


Exhibit 9:



seven are among the top twenty cities used by passengers as transit points. Incidentally, no Canadian cities are among the twenty most frequently used transit points for international passengers.

The third centrality metric used in this report is closeness. Closeness represents the average length of shortest paths between a given city and all others throughout the global airline transportation network. As such, it is a measure of how accessible a city is from others worldwide. Herein, closeness has been calculated accounting for the travel time of each passenger seat entering a given city from all others worldwide. Thus, it accounts for aircraft passenger capacity and the average traveling speed of aircraft. Closeness values have also been normalized between zero (lowest closeness) and one (highest closeness). Exhibit 9 demonstrates that many of the world's major global cities with high in-degree and high betweeness centrality also have high closeness centrality. Among Canadian cities, Toronto has the highest closeness value, ranking 9th worldwide.

Exhibit 10 demonstrates the quarterly volume of international passenger arrivals from 2000 through 2006 by hemisphere. From this figure, it is apparent that international traffic volumes in the northern hemisphere are in the order of ten to twenty times greater than those of the southern hemisphere. Furthermore, passenger flow values in the northern hemisphere vary by roughly twenty-million passengers during the course of a given year, compared with about 1 to 1.5 million passengers in the southern hemisphere. This Exhibit also demonstrates a recurring pattern of flow, with traffic in the northern hemisphere reaching its lowest point during the 1st quarter and gradually rising to its peak in the 3rd quarter. A slightly different pattern is observed in the southern hemisphere with traffic at its lowest point in the 2nd quarter, which then gradually rises to its peak in the 4th quarter. These differences in peaks and nadirs are presumably related to hemispheric differences in climate, which subsequently influence the timings of vacations and travel.

In addition to the recurring pattern of flow during normal circumstances, this Exhibit sheds light on the effects of major international events on worldwide travel patterns. The terrorist attacks in the United States on September 11th, 2001 had a massive impact on worldwide air traffic patterns, evident by the precipitous drop in traffic during the 4th quarter of 2001. Although the recurring pattern of rises and falls in traffic recovered the following quarter, overall levels of international traffic worldwide did not return to their pre 9-11 baseline until three years later in 2004. Another important contributor to the delayed return in air traffic volume was the worldwide outbreak of SARS in 2003. While the outbreak began during the latter part of the 1st quarter, it reached its peak in the 2nd quarter causing traffic flows to markedly drop at that time. This decline in traffic was most notable in East Asia (Exhibit 11) where SARS originated and where a number of cities experienced local outbreaks.

Looking at traffic flows among the world's major cities, Exhibit 12 presents international passenger volumes (i.e. as arrivals plus departures), the global rankings of cities by international volume, and the percent growth in international traffic volume since 2000. This

Exhibit 10:

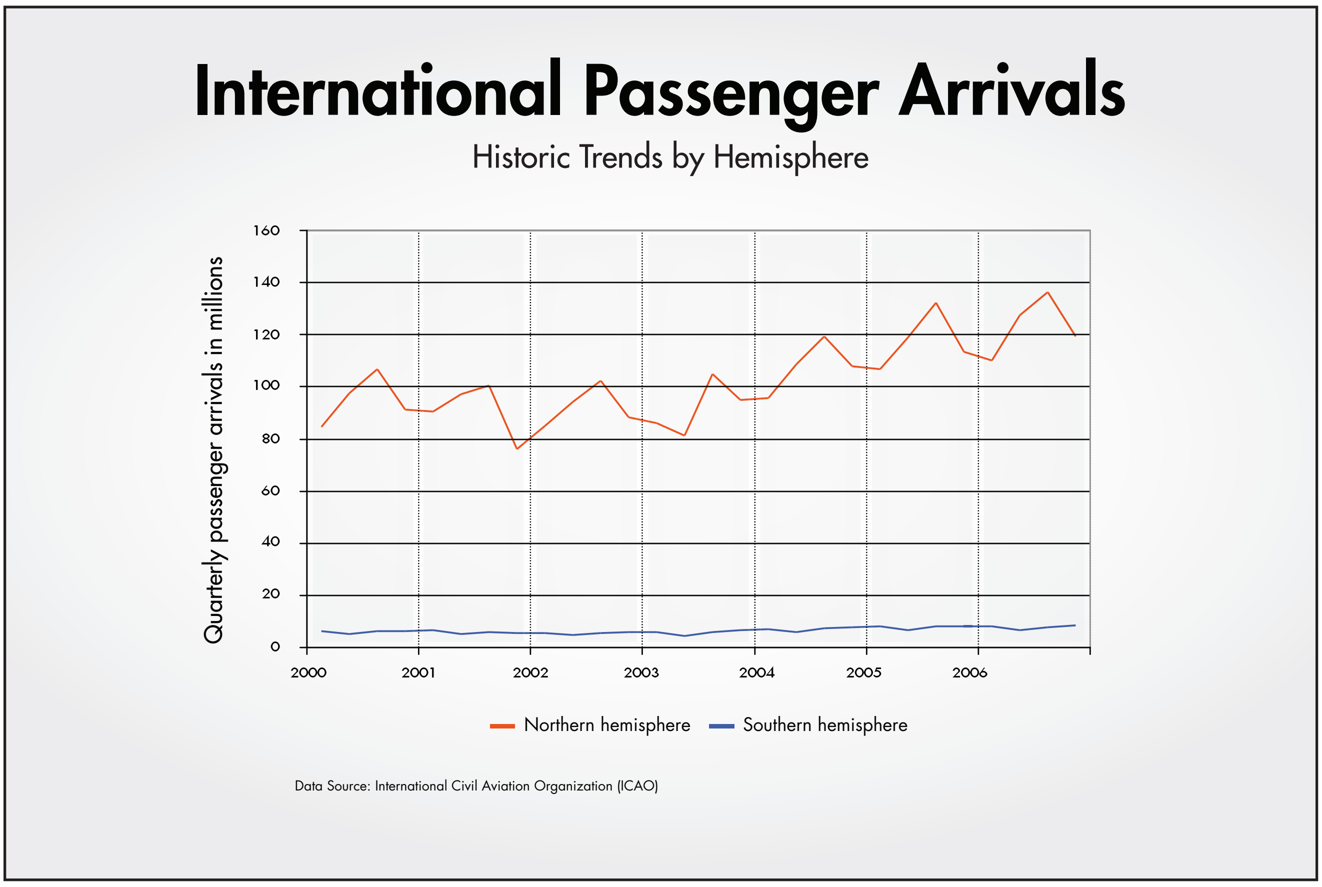


Exhibit 11:

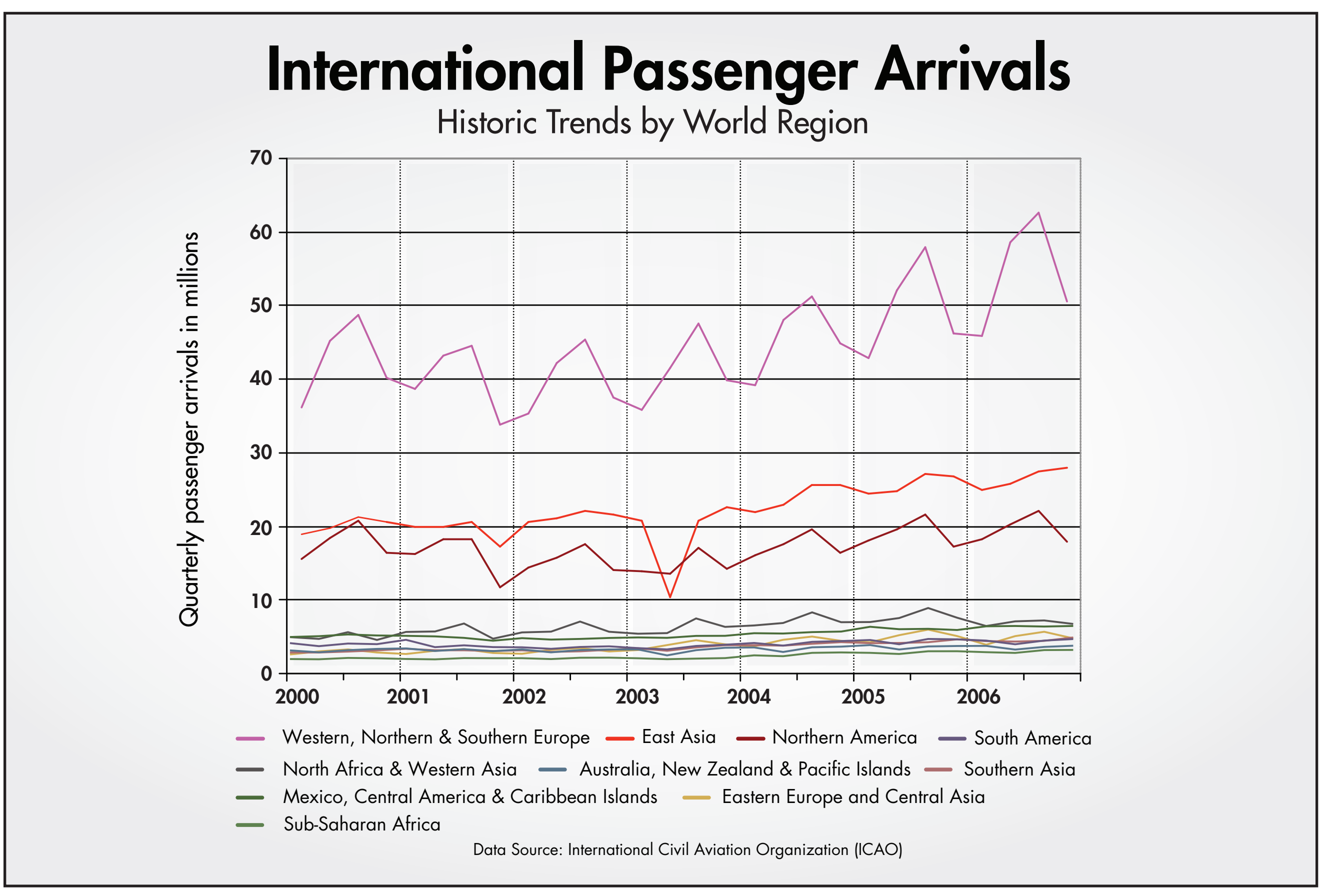


Exhibit 12:

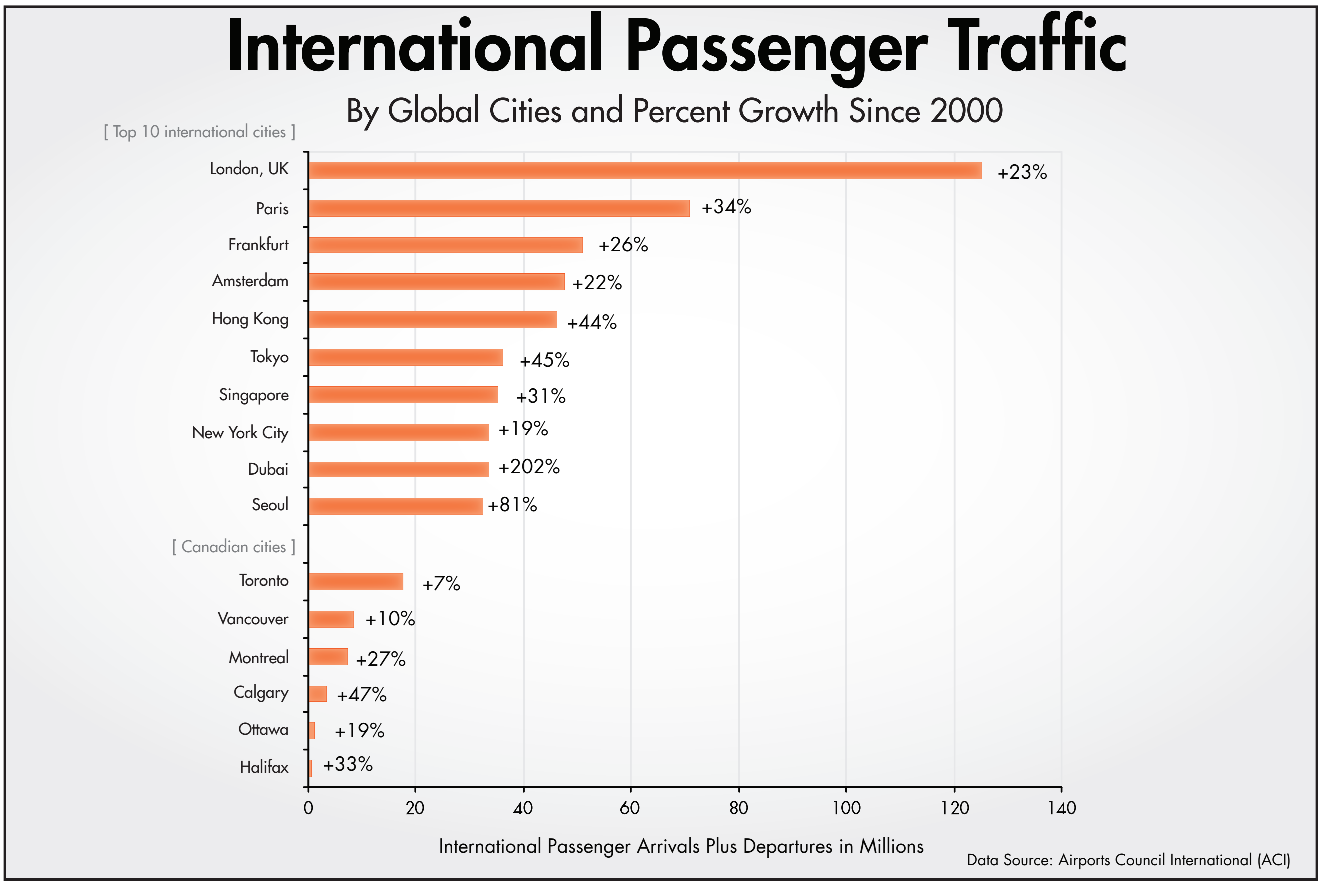


figure demonstrates that London, England receives the highest volume of international air traffic worldwide, followed by Paris, Frankfurt, Amsterdam and Hong Kong. By flows of international passengers, Toronto ranks 24th in the world with 17.7 million passengers, followed by Vancouver (54th in the world with 8.5 million passengers) and Montreal (64th in the world with 7.3 million passengers).

Looking to rapidly evolving cities, Dubai experienced the most dramatic growth in international traffic volume of any city worldwide between the years 2000 and 2007 (201%), followed by Moscow (151%), Seoul (81%) and Madrid (80%). If these cities continue along their current trajectories, their significance in the global airline transportation network and consequently their role as potential importers, exporters, and/or conduits for the spread of emerging infectious diseases will likely rise.

NATIONAL PERSPECTIVES

From only twenty-five commercial airports carrying international passengers to/from the United States and abroad, Canada generates 3.2% of the world's volume of international traffic. The United States, with which Canada shares a long contiguous land border, generates roughly four times Canada's international volume at 13.2% of the world's total. Together, both countries account for one-sixth of the entire world's international traffic volume making the pair particularly vulnerable to the importation of global infectious diseases.

Herein, Canada's connectivity footprint within the global airline transportation network is described.

Exhibit 13 provides a high level overview of the architecture of the airline transportation network within Canada. Specifically, the geographic locations of all cities with commercial airports nationwide are shown and colour coded to illustrate the type flights each city is capable of receiving. For example, cities shown in blue receive domestic flights only and consequently cannot be domestic points of entry for internationally imported infectious diseases. Cities shown in red however, have commercial airports that receive flights from the United States (in addition to Canadian cities) but not other international points of origin. Such cities could act as domestic points of entry for internationally imported infectious diseases, but only if the disease were entering Canada via air travel from the United States. Cities shown in green have the greatest potential to act as entry points for infectious disease threats since they receive flights from domestic, U.S., and non-U.S. international sources.

Given the long contiguous land border shared by the United States and Canada and consequently the potential for infectious diseases to pass between the two countries by land, a number of analyses focusing on the U.S. are shown. For example, Exhibit 14, provides a high level overview of the architecture of the airline transportation network in the United States. The Exhibit is very similar to its Canadian counterpart with the exception that red dots here represent cities that receive flights from Canada, but not other international points of origin. Consistent with the finding that the United States generates roughly four times the Canadian volume of international traffic, this Exhibit reveals that the United States has roughly four times as many cities as Canada that are capable of receiving international flights.

Exhibit 15 illustrates an important metric of Canada's global connectivity. All cities with international airports worldwide are shown in "degrees of separation" from Canada. In this analysis, "separation" is measured by the minimum number of flight connections required to arrive in any Canadian city. In network theory, directly connected nodes in a network tend to have the highest flows between them. With increasing degrees of separation (i.e. increasing number of steps), network flows tend to decrease. Applying this principle, the country appears most vulnerable to infectious disease threats originating in cities shown in red (i.e. from which it has non-stop flights arriving), followed by cities in tan (i.e. from which at least one flight connection is required to arrive in Canada), and finally cities in green and blue (i.e. from which at least two and three flight connections

Exhibit 13: Web Map

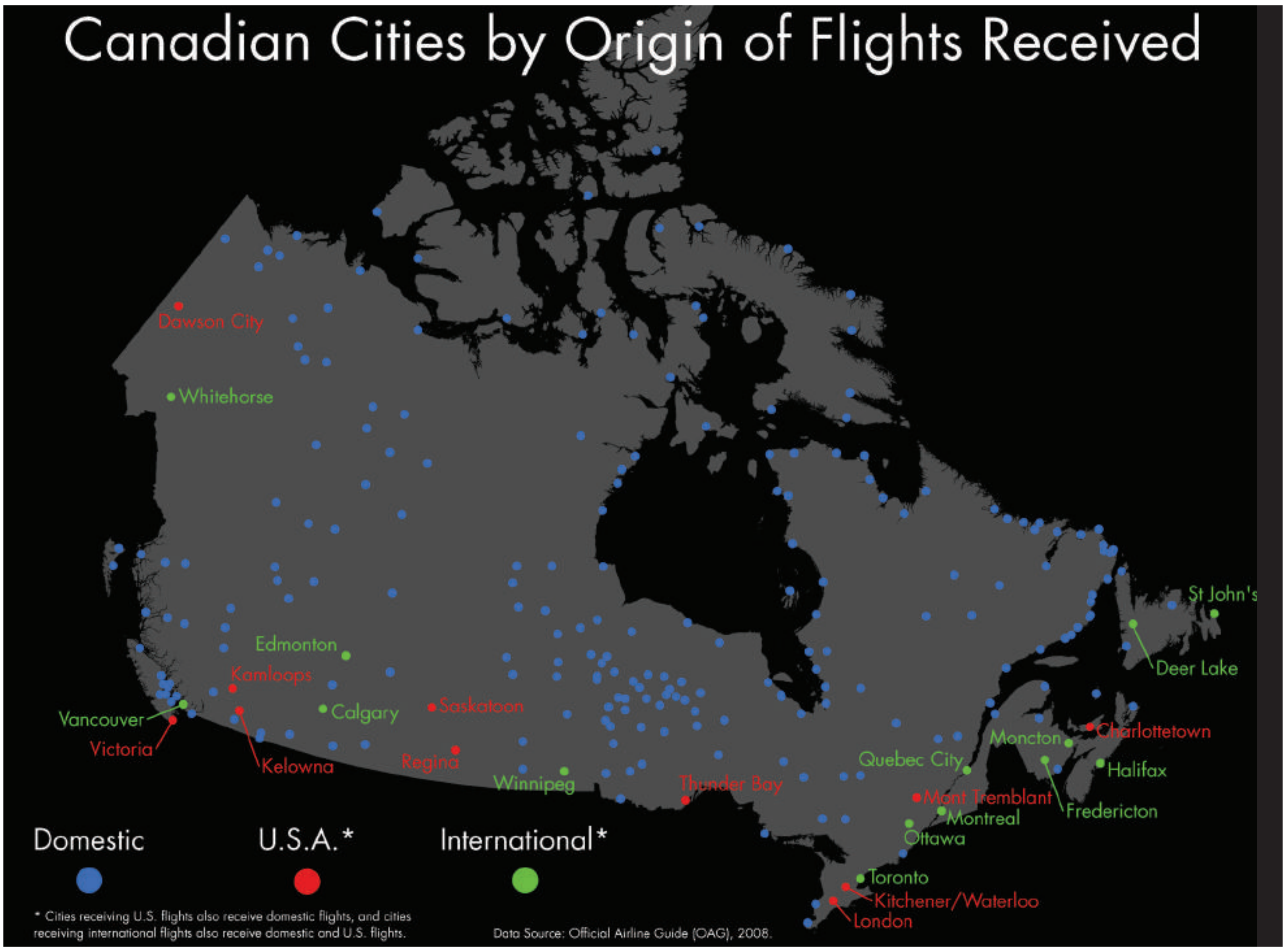


Exhibit 14: Web Map

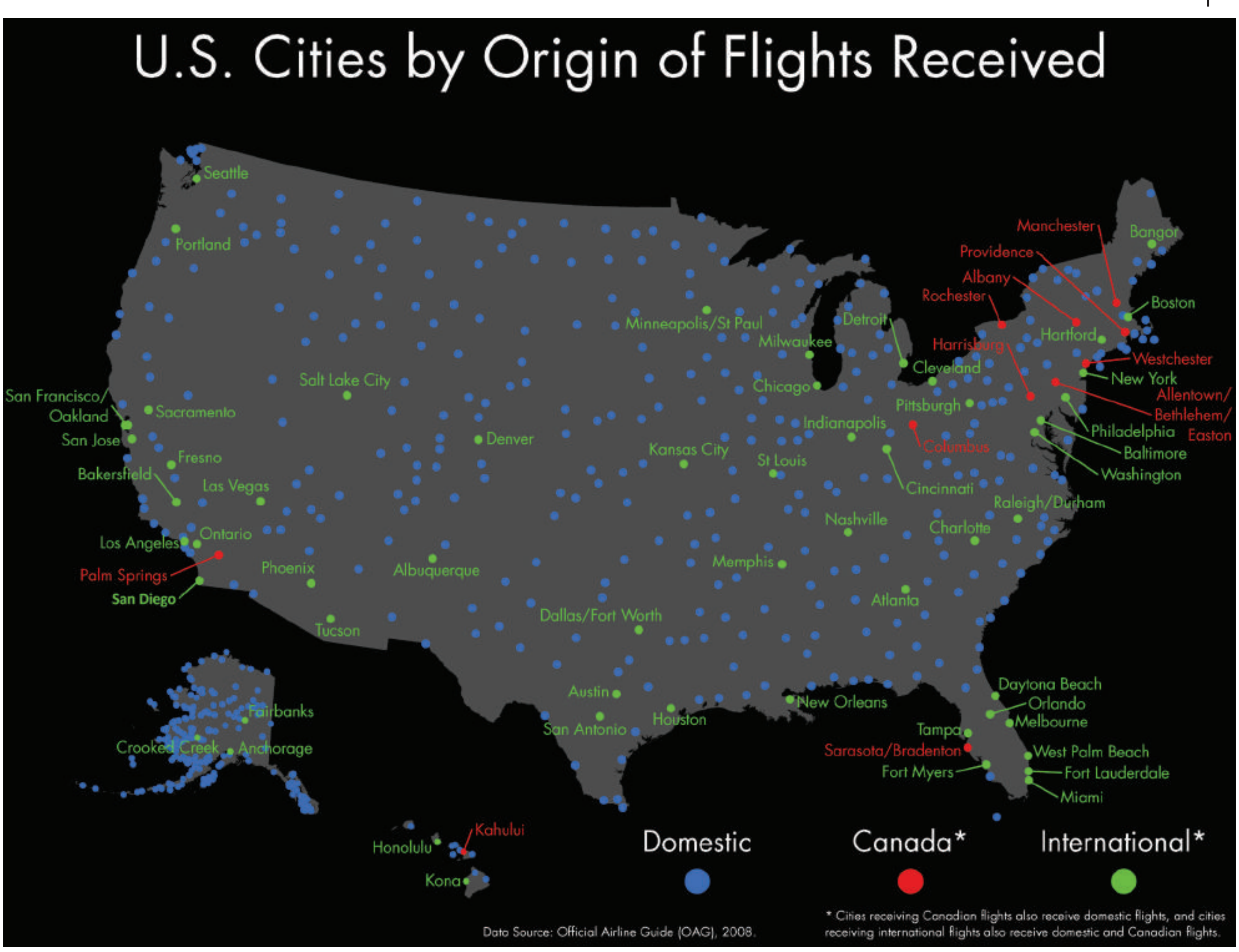


Exhibit 15: Web Map

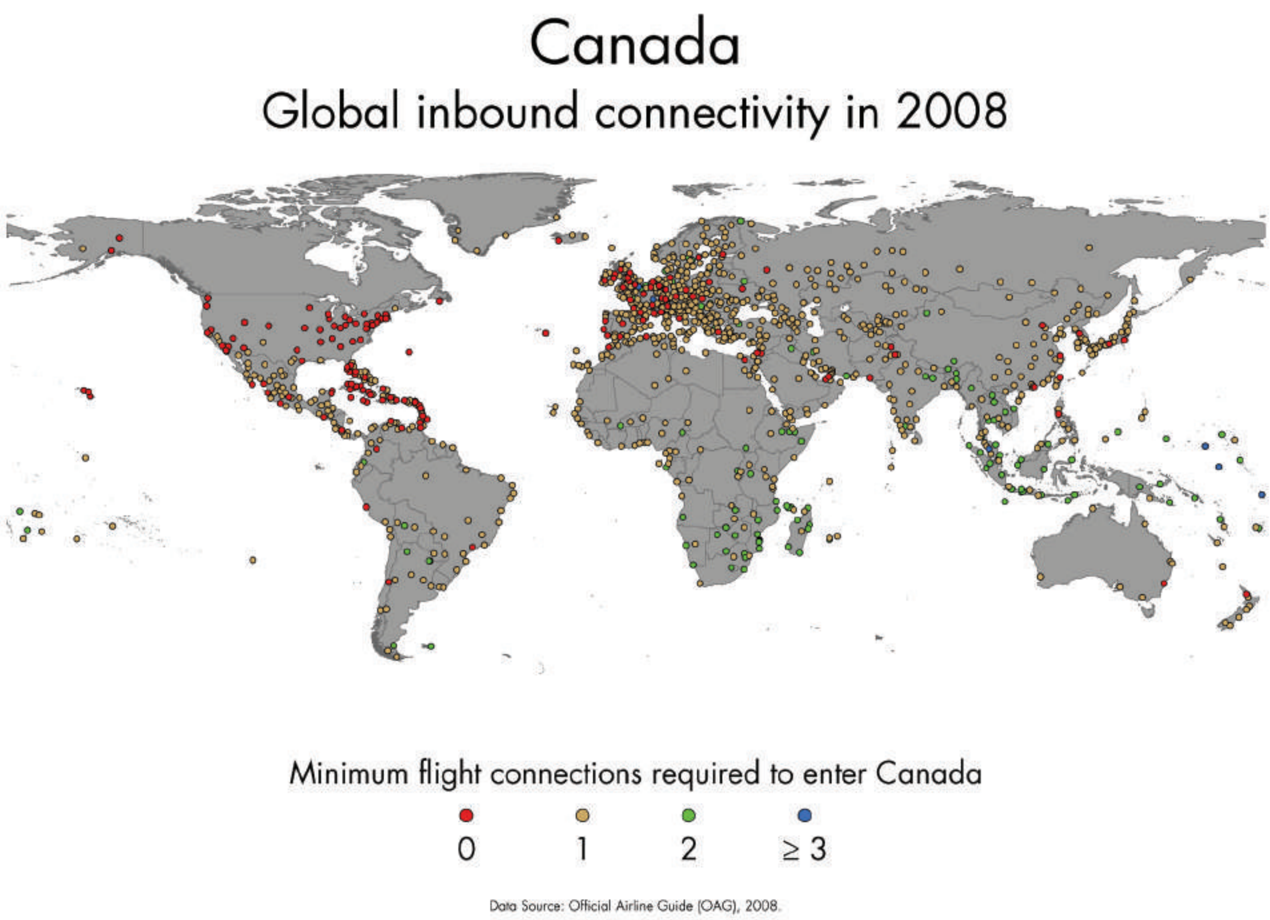
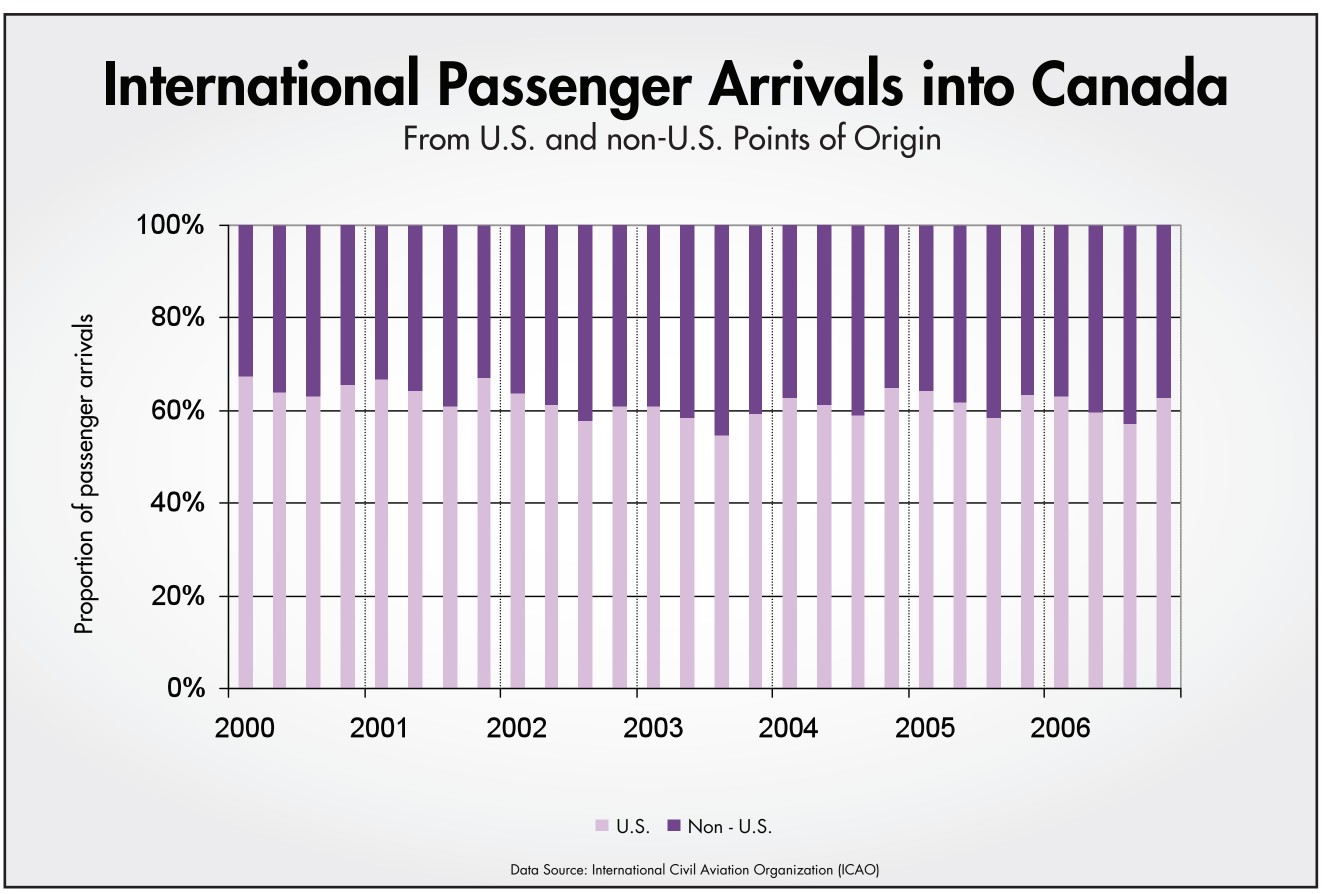


Exhibit 16:



respectively are required to arrive in Canada).

This above principle of "network distance" corresponds with analyzed passenger flow data. For example, 75.4% of Canada's international traffic volume enters the country from cities with which Canada has a non-stop link, while 24.4% originates from cities that are one stop away. Thus, 99.8% of Canada's international passenger arrival flows originate from cities that the country is either directly connected to, or that are reachable with one flight connection.

Exhibit 16 demonstrates the proportion of international traffic originating from the United States and other non-U.S. points of origin between 2000 and 2006. On average, sixty percent of Canada's international passenger flows originate from the United States with the remainder coming from the rest of the world.

Exhibit 17 demonstrates that in 2007 more than half of Canada's international passengers arrived from the United States (51.0%), followed by the United Kingdom (6.6%), China (4.3%), Mexico (3.6%), France (3.4%), and Germany (2.4%). From within China, Hong Kong generates a higher volume of international passenger arrivals into Canada (2.2%) than the rest of mainland China combined (2.1%). If the European Union is analyzed as a single entity, it produces 19.3% of Canada's total volume of international passenger arrivals. Of note, over four-fifths of Canada's total inbound volume of international traffic originates from just thirteen countries.

Exhibit 18 geographically illustrates which countries of the world generate the greatest volume of international passengers arriving into Canada.

Of the thirteen leading national sources of international traffic into Canada, two have highly irregular flow patterns during the course of the year. Mexico, which produces the 4th largest volume of international passengers into Canada, generates most of its traffic from Cancun, Puerto Vallarta and Mexico City. Among these three cities, traffic into Canada from Cancun and Puerto Vallarta surges between the months of January and April and then declines substantially for the remainder of the year. Traffic into Canada from Mexico City demonstrates significantly less variance. Likewise, traffic into Canada from Cuba follows a similar first quarter pattern. This suggests that first quarter traffic from these two countries is largely generated by Canadians returning from winter or spring vacations.

Exhibit 19 is a heat-map that spatially depicts a continuum of where passengers most frequently originate from worldwide when traveling into Canada. As indicated in the methods section of this report, hot-spots in the map reflect the true origins of passengers since travel routes, including all flight connections, are accounted for. When reading the heat-maps in this report, readers should first examine the Volume of Passenger Arrivals bar to assess the magnitude of passenger flows represented by the "hottest" spots on the map. Every heat-map is unique in this regard, and reflects the relative flows of passengers. Consequently, different heat-maps should not be compared directly with one another, but rather interpreted independently.

Exhibit 17:

Leading International Sources of Passenger Traffic into Canada

Ranking	Country	Annual Volume of Passengers	Percentage of Canadian Annual Volume	Cumulative Percentage of Canadian Annual Volume
1	United States of America	9,320,119	51.0%	51.0%
2	United Kingdom	1,203,272	6.6%	57.6%
3	China (including Hong Kong)	786,569	4.3%	61.9%
4	Mexico	655,219	3.6%	65.5%
5	France	622,657	3.4%	68.9%
6	Germany	429,057	2.4%	71.3%
7	Japan	345,536	1.9%	73.2%
8	India	331,678	1.8%	75.0%
9	Italy	289,723	1.6%	76.6%
10	South Korea	219,331	1.2%	77.8%
11	Netherlands	183,682	1.0%	78.8%
12	Cuba	177,145	1.0%	79.8%
13	Philippines	155,461	0.9%	80.7%

Data Source: International Air Transport Association (IATA), 2007

Exhibit 20 quantifies the volume of international passenger traffic entering Canada from the world's top twenty-five cities excluding those in i) the United States and ii) Western, Southern, and Northern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Exhibit 21 offers a point of entry perspective to passenger flows by displaying international traffic volumes entering Canadian and U.S. cities. Bars in this three dimensional map represent the total volumes of international traffic entering Canada and the U.S. from around the world, after excluding passenger movements between the two countries. New York City has by far the greatest volume of international passenger arrivals among Canadian and U.S. cities with 13.3 million passengers in 2007, followed by Los Angeles (6.5 million passengers), Miami (5.3 million passengers), Toronto (3.5 million passengers), San Francisco (3.5 million passengers), and Chicago (2.8 million passengers). Vancouver and Montreal have significantly lower volumes, but still rank relatively high (Vancouver with 1.8 million passengers; ranked 10th and Montreal with 1.7 million passengers; ranked 13th).

Exhibit 18: Web Map

Volume of International Passenger Arrivals into Canada by Source Country in 2007

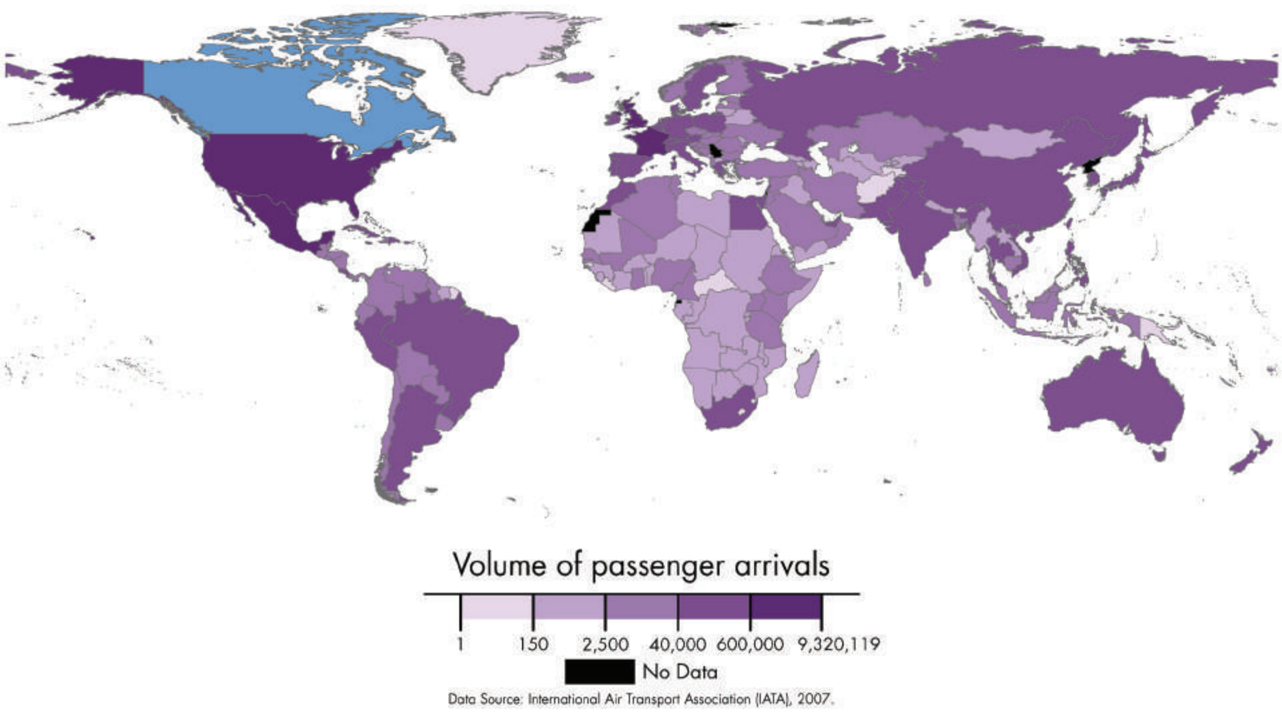


Exhibit 19: Web Map

Canada

Global areas of high inbound passenger flow in 2007

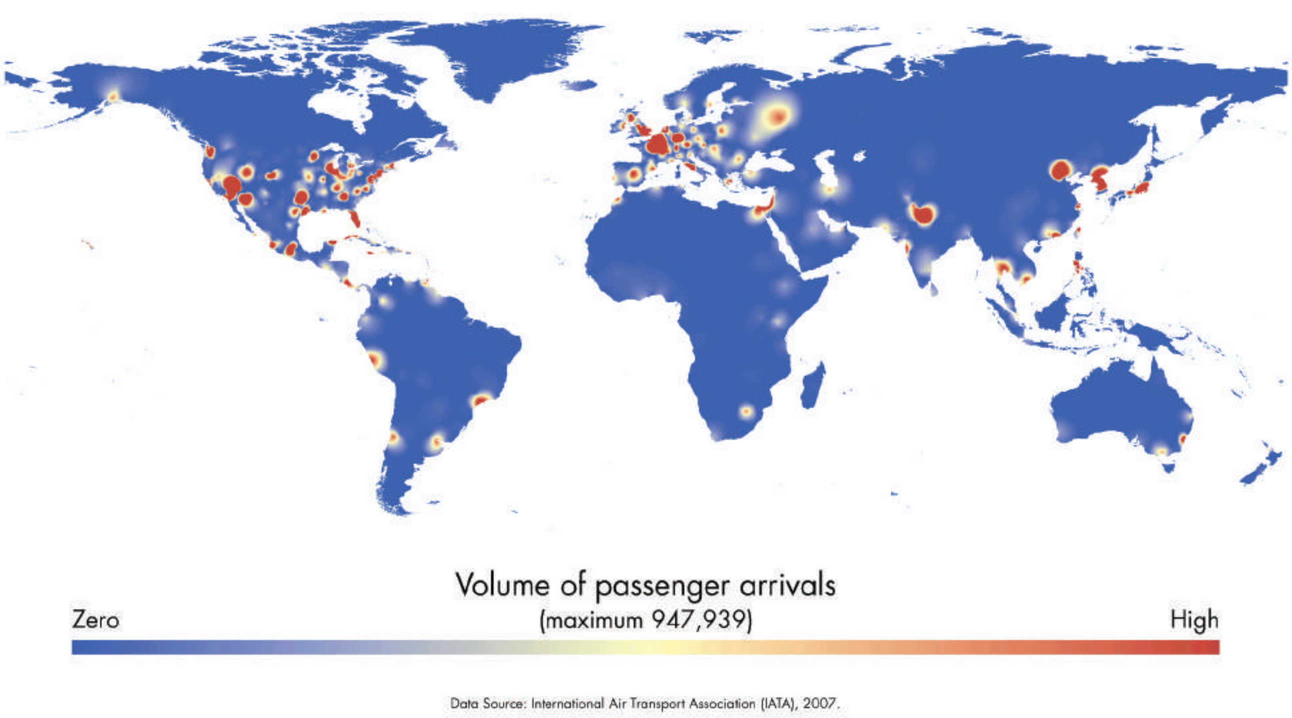


Exhibit 20:

CANADA: Volume of International Passenger Arrivals from Leading Global Points of Origin*

City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Hong Kong	Hong Kong (sar) China	395500	7.7%	7.7%
Tokyo	Japan	221880	4.3%	12.0%
Seoul	Korea, Republic of	209708	4.1%	16.1%
Mexico City	Mexico	187649	3.7%	19.8%
Cancun	Mexico	177119	3.5%	23.2%
Beijing	China	176364	3.4%	26.7%
Delhi	India	162878	3.2%	29.9%
Manila	Philippines	145608	2.8%	32.7%
Shanghai	China	139956	2.7%	35.4%
Taipei	Chinese Taipei	106540	2.1%	37.5%
Puerto Vallarta	Mexico	105615	2.1%	39.6%
Tel Aviv	Israel	94922	1.9%	41.4%
Montego Bay	Jamaica	92322	1.8%	43.2%
Osaka	Japan	70770	1.4%	44.6%
Nassau	Bahamas	61622	1.2%	45.8%
Mumbai	India	60830	1.2%	47.0%
Dubai	United Arab Emirates	59886	1.2%	48.2%
Sao Paulo	Brazil	58102	1.1%	49.3%
Punta Cana	Dominican Republic	57809	1.1%	50.4%
Kingston	Jamaica	56027	1.1%	51.5%
Port of Spain	Trinidad and Tobago	55775	1.1%	52.6%
San Juan	Puerto Rico	55143	1.1%	53.7%
Barbados	Barbados	54801	1.1%	54.8%
Bangkok	Thailand	53621	1.0%	55.8%
Varadero	Cuba	52462	1.0%	56.8%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

REGIONAL PERSPECTIVES

The overwhelming majority of international traffic entering Canada passes through a limited number of urban centres. Of all international passengers to Canada from developing areas of the world, more than eighty percent arrive in just three Canadian cities. More than one-third (36.6%) of such passengers arrive in Toronto, one-fifth (20.0%) in Vancouver, and one-sixth (16.1%) in Montreal.

A series of regional and municipal analyses are presented to identify important national differences in global connectivity. Sub-group analyses have been performed for seven regions and six major cities across Canada as previously described. These data are presented to facilitate discussions between federal, provincial-territorial, and municipal stakeholders.

Exhibit 22 demonstrates the global in-degree centrality of six major cities across Canada, representing the total number of non-stop routes into these cities from any point of origin worldwide. To provide further detail, in-degree centrality values are separated into domestic, U.S., and non-U.S. international routes. Toronto has the highest overall in-degree centrality, followed by Montreal, and then Vancouver.

Exhibit 23 presents information on precisely where non-stop routes into Canada's major cities originate from. For example, Vancouver does not have the country's highest overall international in-degree centrality, but it does have the greatest number of non-stop links with i) East Asia, and ii) Australia, New Zealand and the Pacific. This Exhibit allows readers to evaluate the nature of connectivity between the ten regions of the world and six major Canadian cities shown.

Exhibit 24 provides a temporal perspective to the seasonal patterns of international traffic (i.e. arrivals plus departures) among six of Canada's major cities. Traffic disruption after the 9-11-2001 terrorist attacks and during the 2003 worldwide outbreak of SARS is most apparent in the cities of Toronto and Vancouver.

Ontario

Exhibit 25 illustrates an important metric of global connectivity. All cities with international airports worldwide are shown in "degrees of separation" from Ontario. In this analysis, "degrees of separation" are measured by the minimum number of flight connections required to land in any city across Ontario. In network theory, directly connected nodes within a network tend to have the highest flows between them. With increasing degrees of separation (i.e. increasing number of steps) between nodes, network flows tend to decrease. In the case of Ontario, the province is most vulnerable to infectious disease threats originating in cities shown in red (i.e. from which it has non-stop flights arriving), followed by cities in tan (i.e. from which at least one flight connection is required to enter Ontario), and finally cities in green and blue (i.e. from which at least two and three flight connections respectively are required to enter Ontario).

Exhibit 26 complements the findings of the previous Exhibit by illustrating areas of the world where passengers most frequently originate when traveling to Ontario. It is important

Exhibit 21:

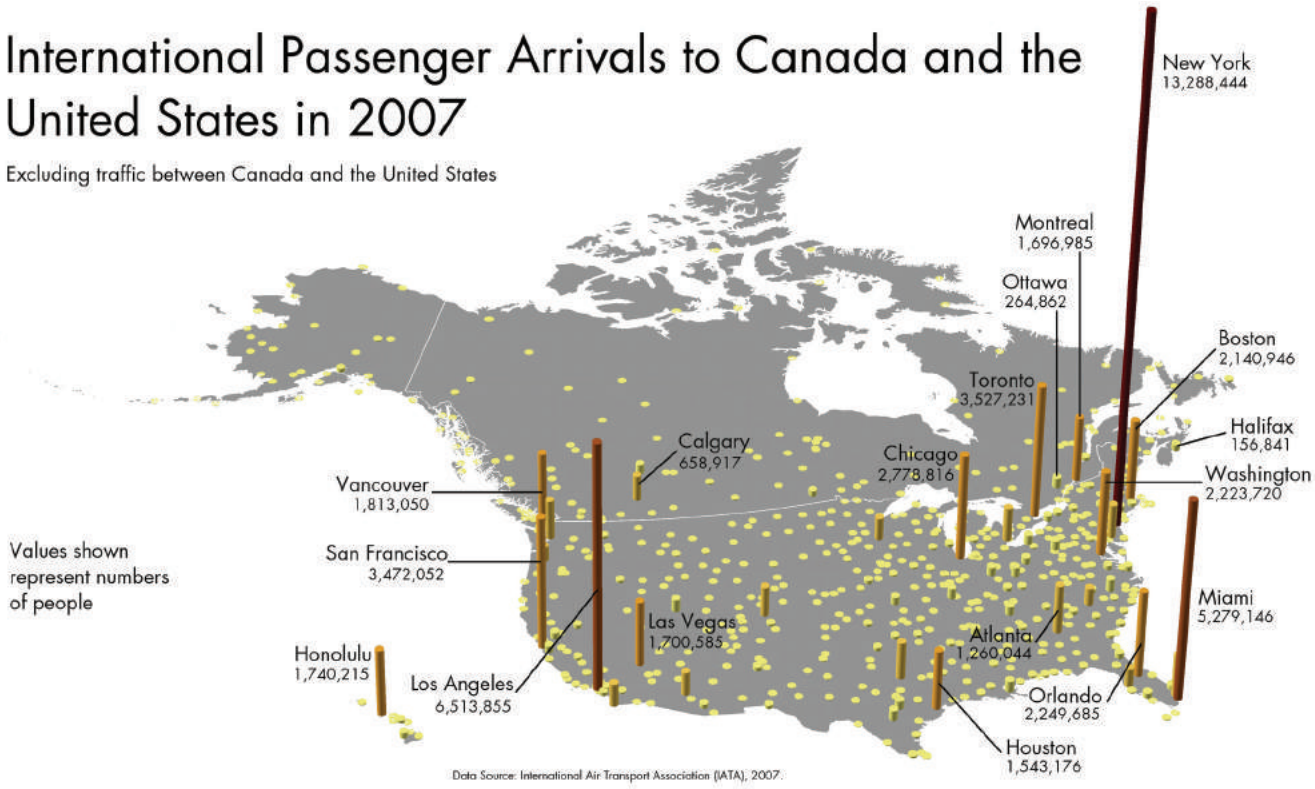


Exhibit 22:

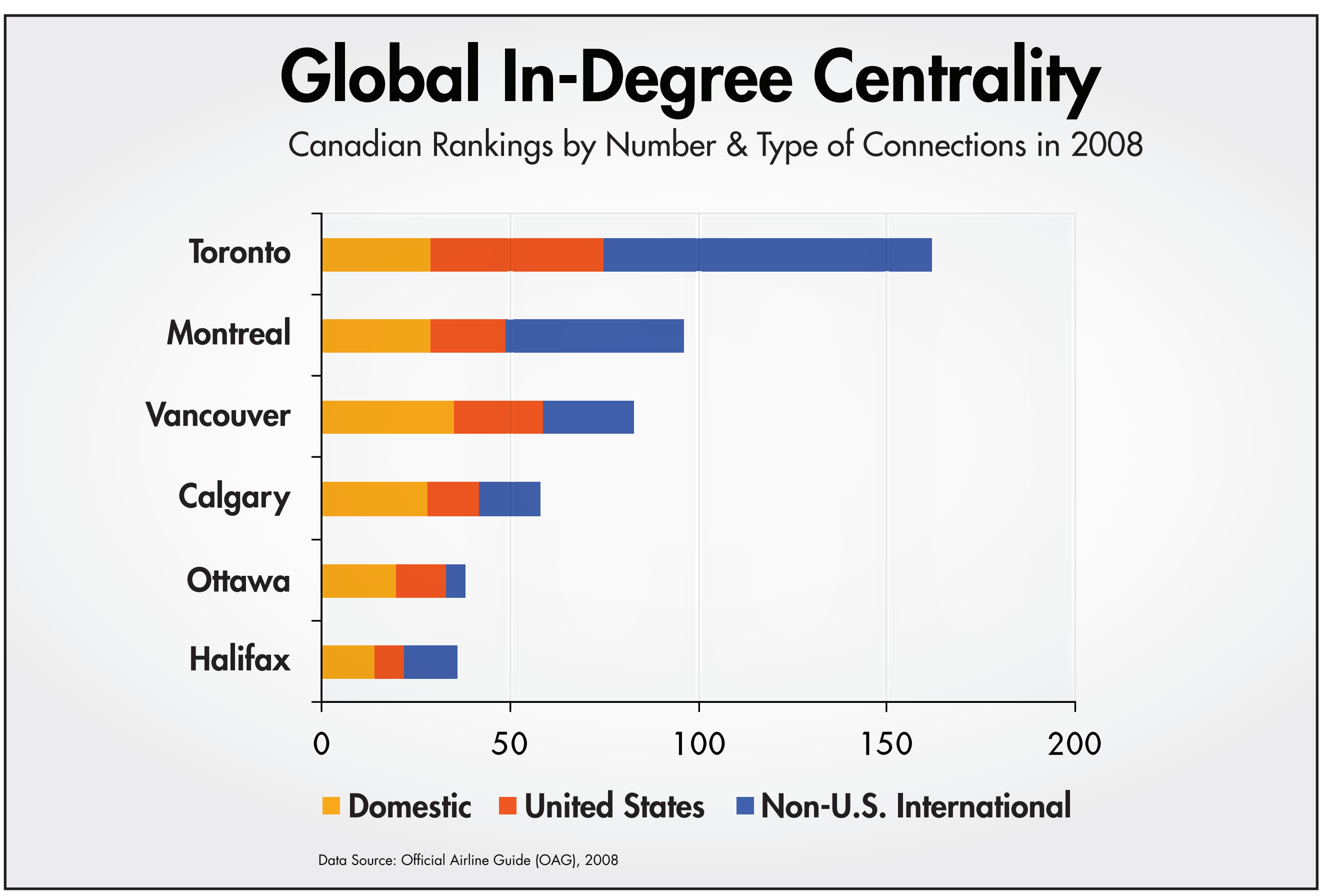


Exhibit 23:

International In-Degree Centrality of Canadian Cities by World Region						
World Region	Toronto	Montreal	Vancouver	Calgary	Halifax	Ottawa
Northern America	47	21	24	14	10	13
Western, Northern & Southern Europe	34	22	9	7	4	3
Mexico, Central America & Caribbean	31	19	5	9	8	2
East Asia	5	0	8	0	0	0
North Africa & Western Asia	3	4	0	0	0	0
Eastern Europe & Central Asia	5	1	0	0	0	0
South America	5	0	0	0	0	0
Southern Asia	3	0	0	0	0	0
Australia, New Zealand & Pacific Islands	0	0	2	0	0	0
Sub-Saharan Africa	0	0	0	0	0	0
Total	133	67	48	30	22	18

Data Source: Official Airline Guide, 2008

Exhibit 24:

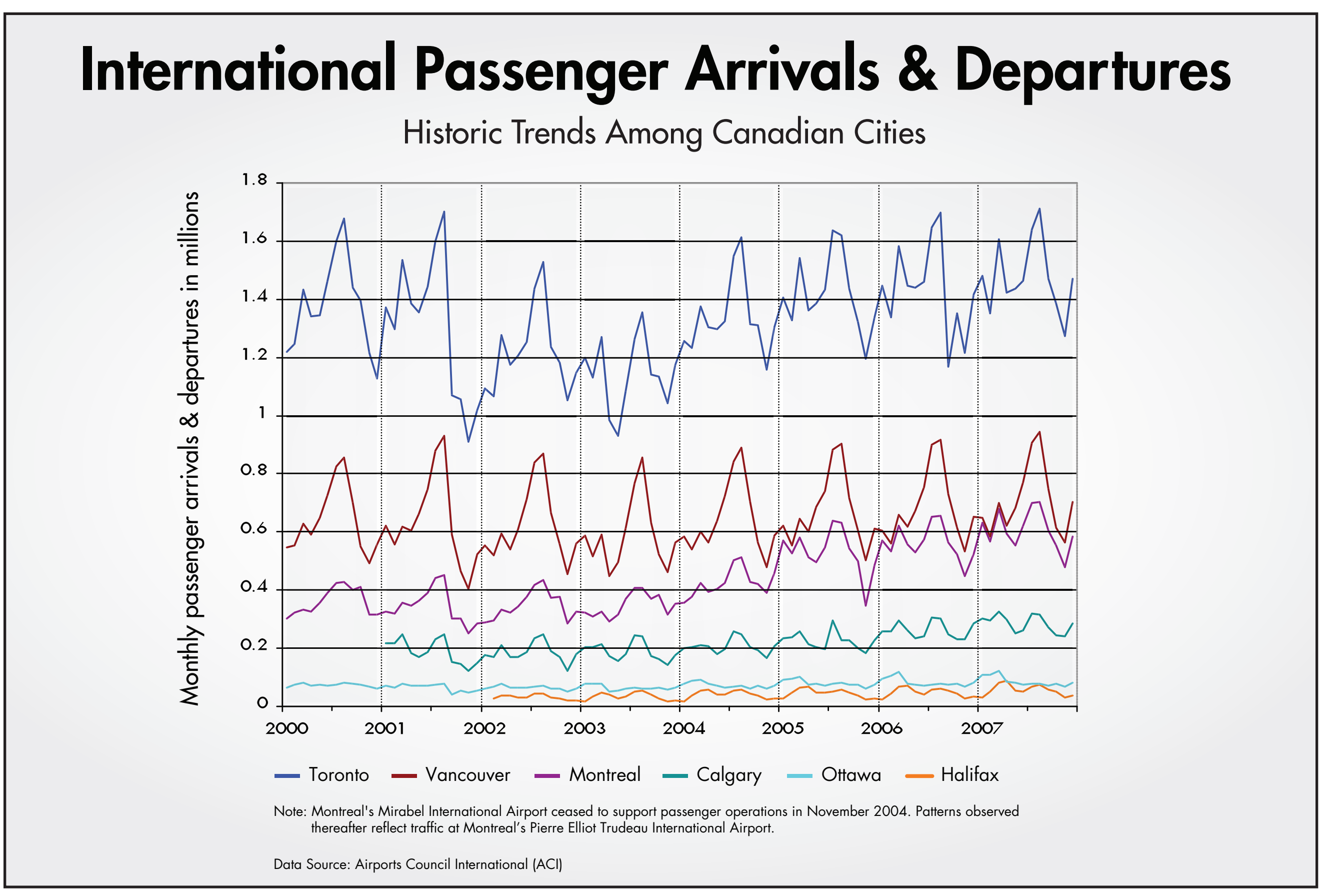


Exhibit 25: Web Map

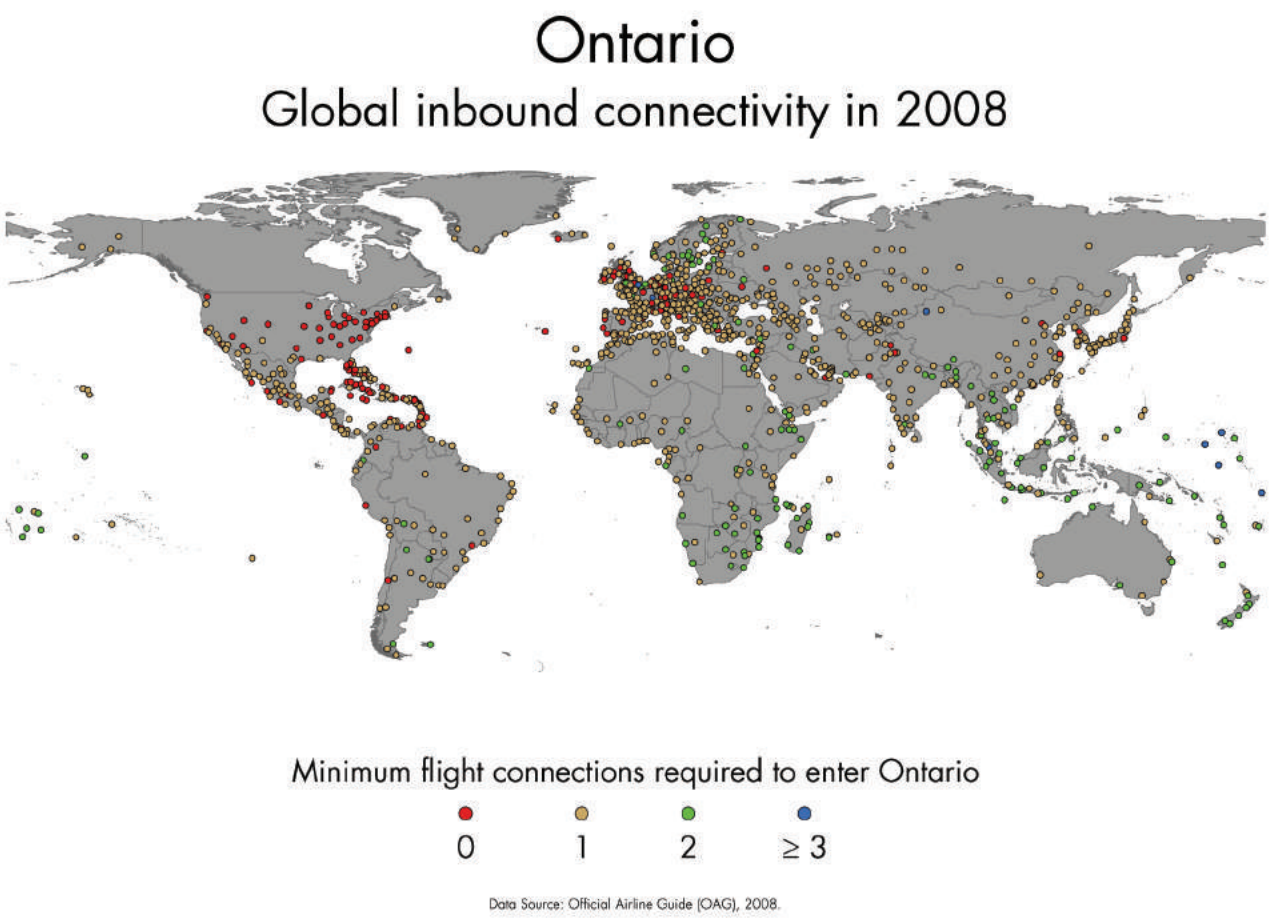
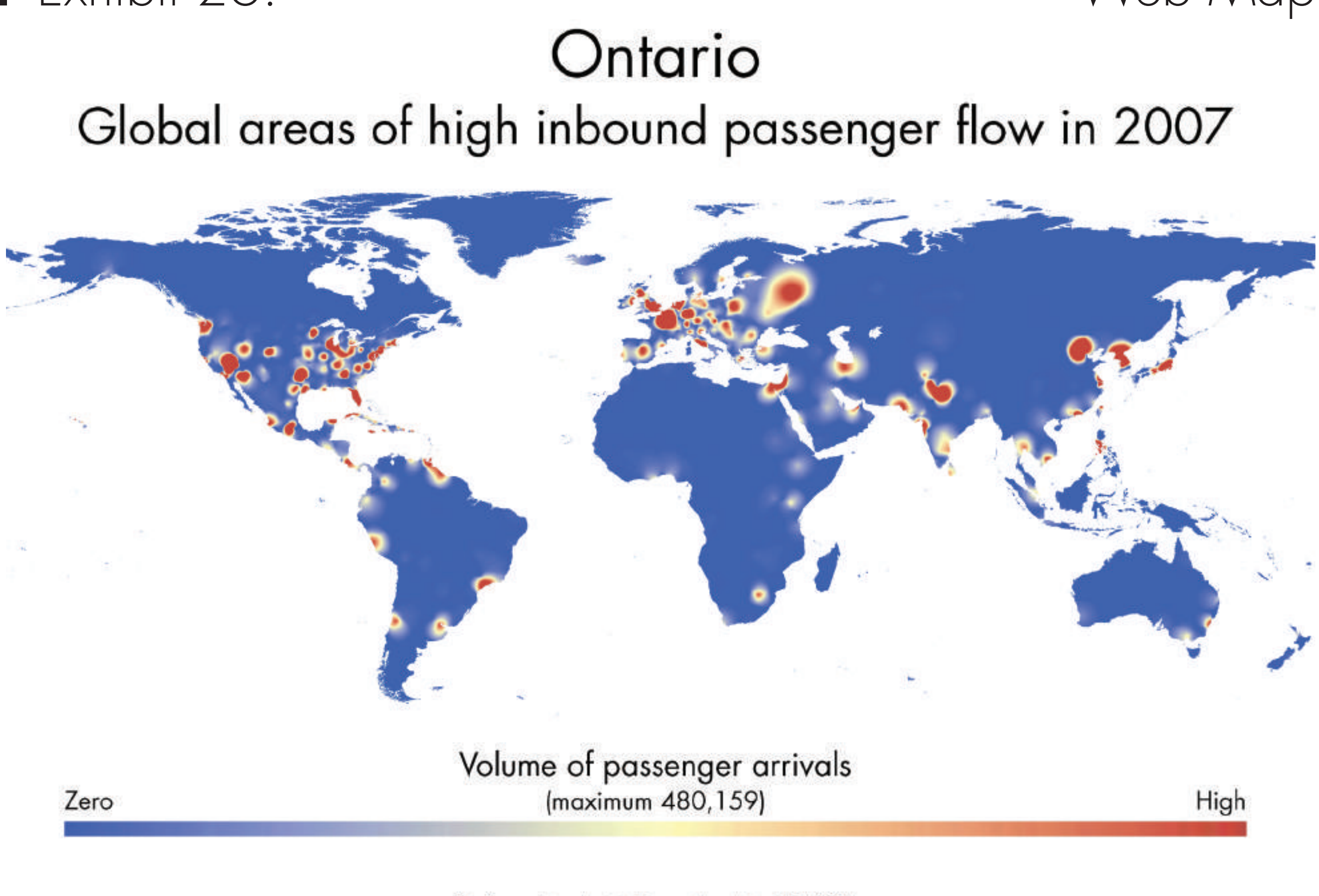


Exhibit 26: Web Map



to note that hot-spots shown in this map reflect the true origins of international passengers in that all flight connections (if applicable) for each passenger trip have been accounted for. Since this type of map was designed as a visual aid, it should not be used to delineate the precise geographic boundaries of hot-spots. When interpreting this type of heat-map, readers should first examine the Volume of Passenger Arrivals bar to determine the maximum number of passengers represented by the map's hot-spots. Furthermore, different heat-maps should not be compared with one another, but rather interpreted independently. Complementing this heat-map is Exhibit 27, which shows the number of international passengers entering Ontario from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Toronto

Exhibit 28 illustrates the flow of international and domestic passengers entering Toronto since the year 2000. Recurring seasonal patterns are observed with notable disruptions after the terrorist attacks of 9-11-2001 in the United States and during the 2003 worldwide outbreak of SARS. Complementing this figure is Exhibit 29 which quantifies the proportion of international traffic entering Toronto from the United States and other non-U.S. points of origin over time. From this figure, it is apparent that approximately sixty percent of Toronto's international traffic originates in the United States. Exhibit 30 spatially depicts areas of the world where passengers most frequently originate when traveling to Toronto as a heat-map. Exhibit 31 shows the number of international passengers entering Toronto from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Exhibit 32 provides information on the preferred routes used by international passengers arriving in Toronto when departing from different regions of the world. This information has been presented to identify all available frontiers for disease control. In the case of travelers arriving into Toronto through non-stop flights, public health control measures are limited to the origin of the infectious disease threat and/or the domestic point of entry within Canada. For those traveling indirectly (i.e. requiring multiple flights), major transit points where flight connections are made represent another potential frontier for intervention. In these Exhibits, the top five international and/or domestic cities used by passengers as transit points en route to Toronto are shown.

Ottawa

Exhibit 33 illustrates the flow of international and domestic passengers entering Ottawa since the year 2000. Recurring seasonal patterns are observed with notable disruptions after the terrorist attacks of 9-11-2001 in the United States and to a lesser degree the 2003 worldwide outbreak of SARS. Complementing this figure is Exhibit 34 which quantifies the proportion of international traffic entering Ottawa from the United States and other non-U.S. points of origin over time. From this figure, it is apparent that approximately eighty percent of Ottawa's

Exhibit 27:

Ontario - Volume of International Passenger Arrivals from Leading Global Points of Origin*				
City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Hong Kong	Hong Kong (sar) China	149757	6.5%	6.5%
Mexico City	Mexico	76135	3.3%	9.8%
Beijing	China	75302	3.3%	13.1%
Tokyo	Japan	71455	3.1%	16.2%
Delhi	India	70573	3.1%	19.3%
Montego Bay	Jamaica	68743	3.0%	22.3%
Cancun	Mexico	68205	3.0%	25.2%
Tel Aviv	Israel	63822	2.8%	28.0%
Seoul	Korea, Republic of	62275	2.7%	30.7%
Manila	Philippines	57408	2.5%	33.2%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 28:

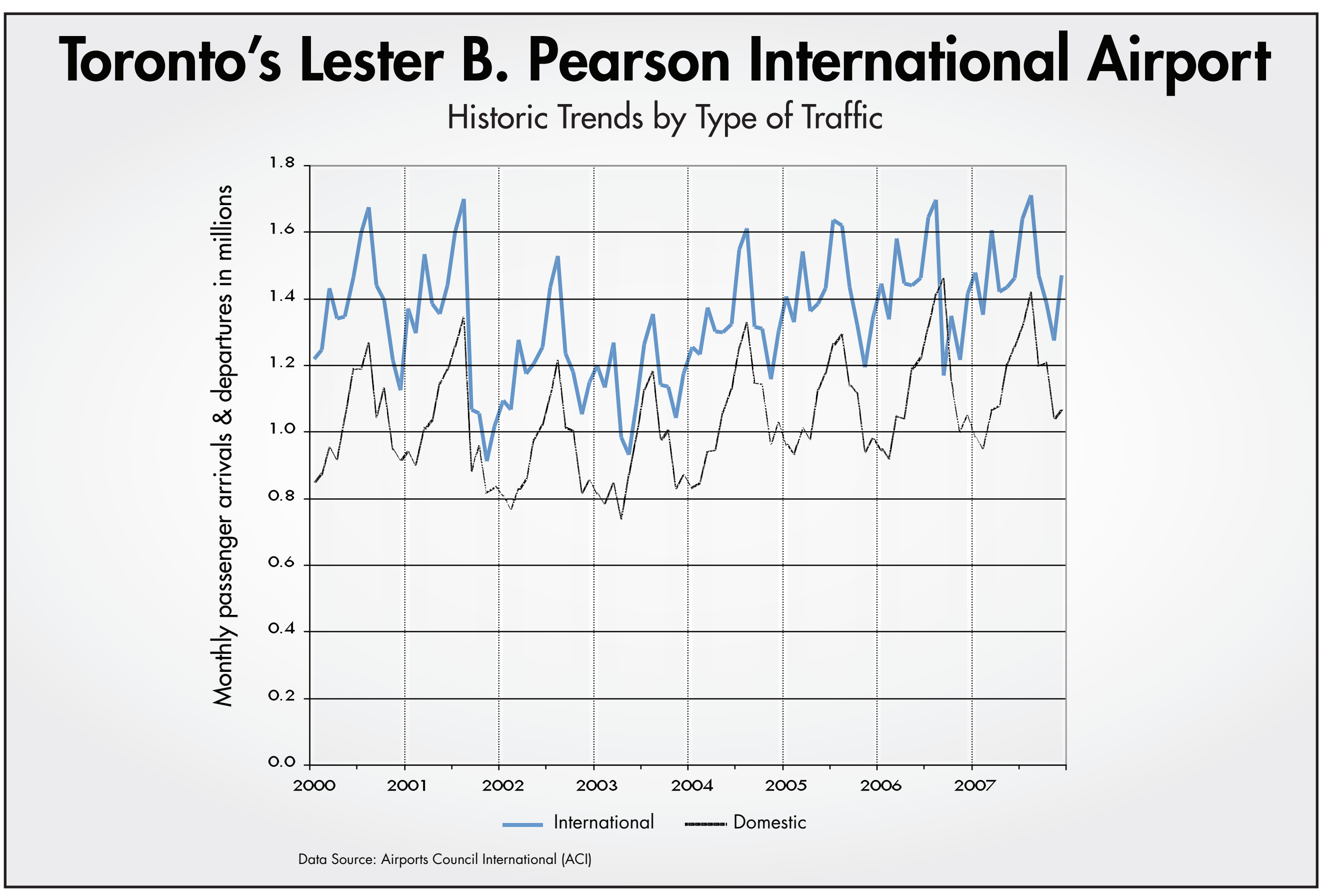


Exhibit 29:

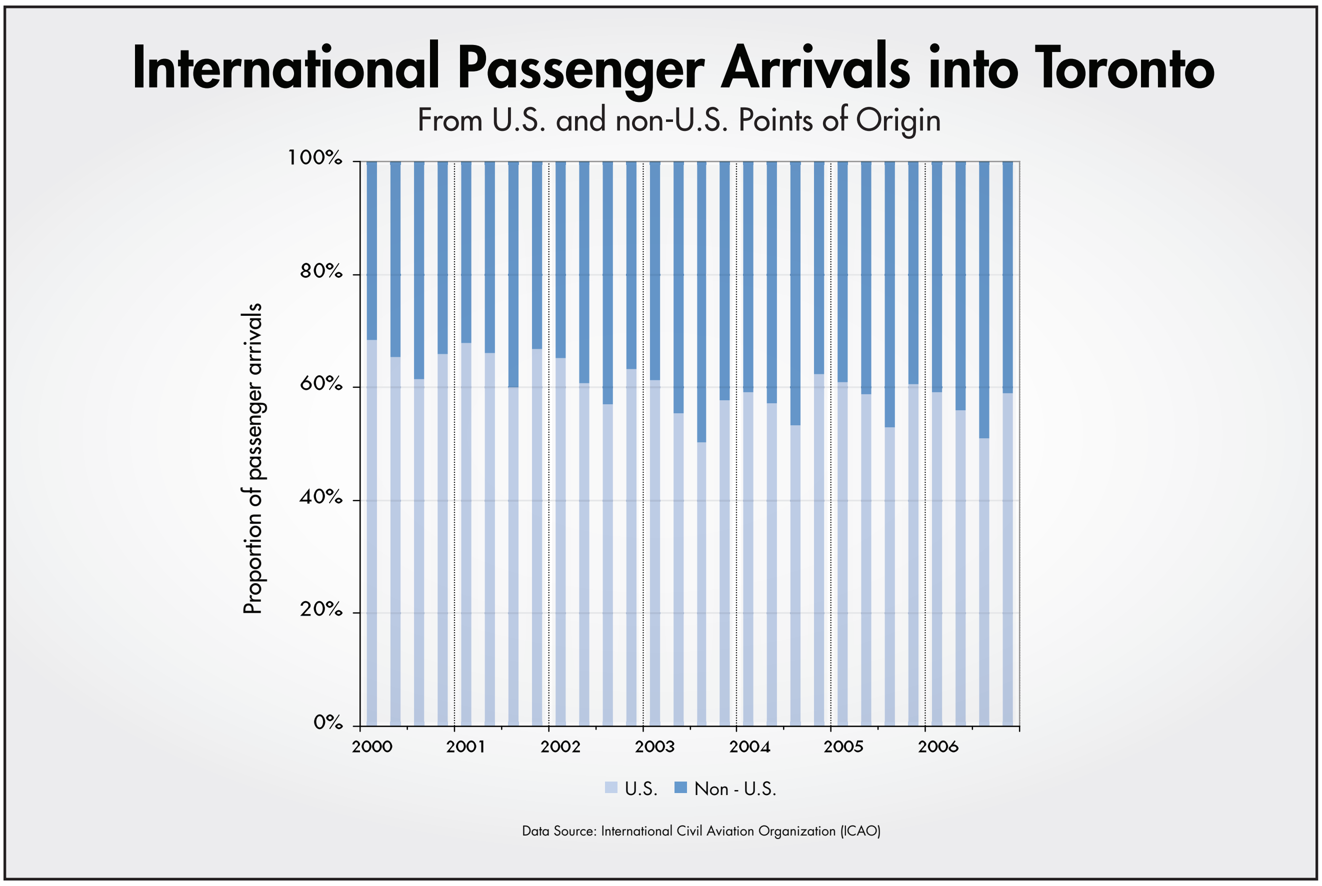


Exhibit 30: Web Map

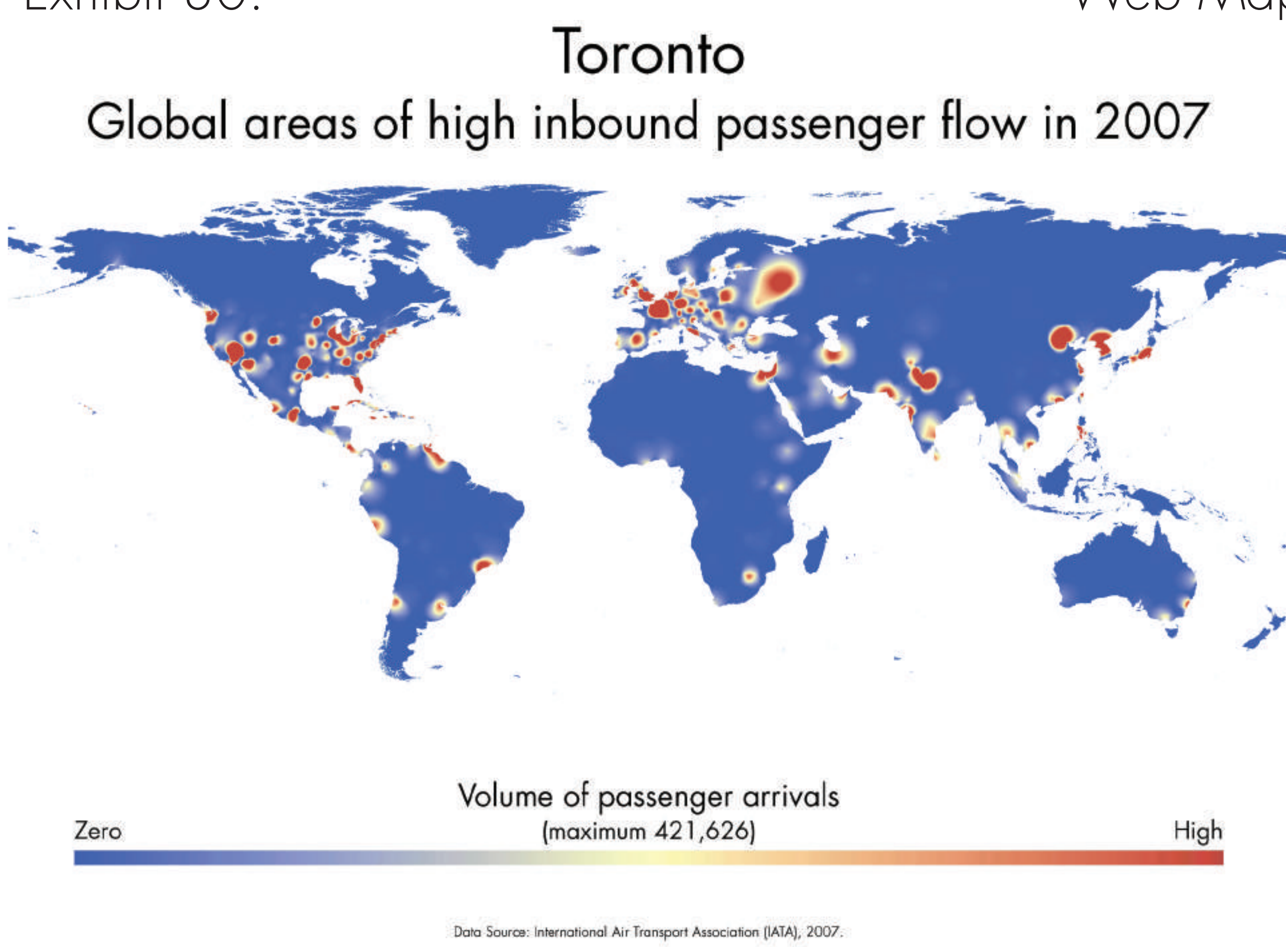


Exhibit 31:

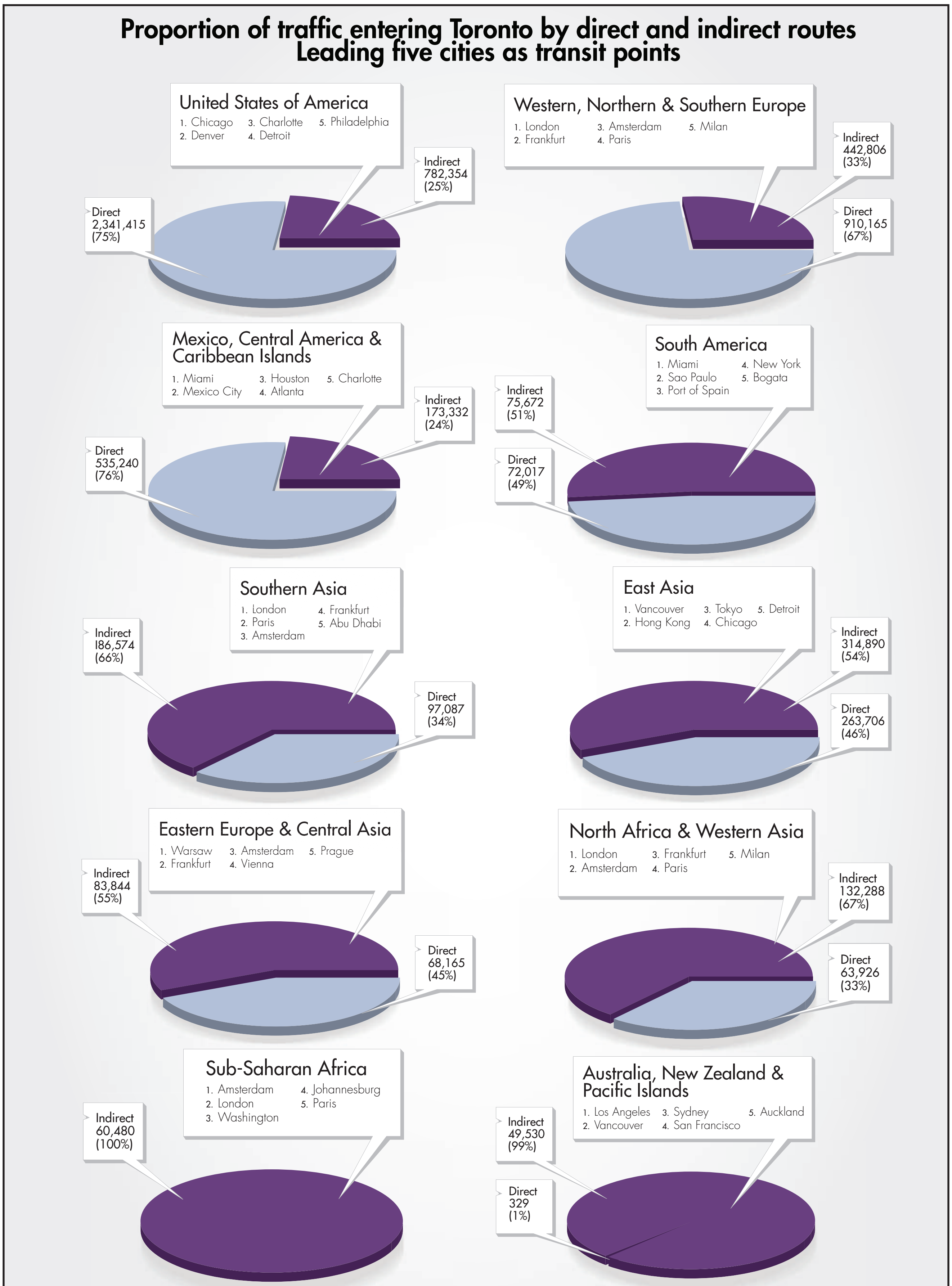
Toronto - Volume of International Passenger Arrivals from Leading Global Points of Origin*

City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Hong Kong	Hong Kong (sar) China	144072	6.8%	6.8%
Mexico City	Mexico	70078	3.3%	10.1%
Delhi	India	67554	3.2%	13.2%
Beijing	China	66377	3.1%	16.4%
Tokyo	Japan	65560	3.1%	19.4%
Montego Bay	Jamaica	65081	3.1%	22.5%
Tel Aviv	Israel	61606	2.9%	25.4%
Seoul	Korea, Republic of	58249	2.7%	28.1%
Cancun	Mexico	55849	2.6%	30.8%
Manila	Philippines	54975	2.6%	33.3%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 32:



Passenger arrivals are categorized here as direct (no flight connections used) or indirect (at least one flight connection used). The five cities most frequently used as transit points along indirect routes are shown for each world region. Values in each pie graph represent the number of international passengers arriving into Toronto by world region in 2007.

Data Source: International Air Transport Association (IATA), 2007

Exhibit 33:

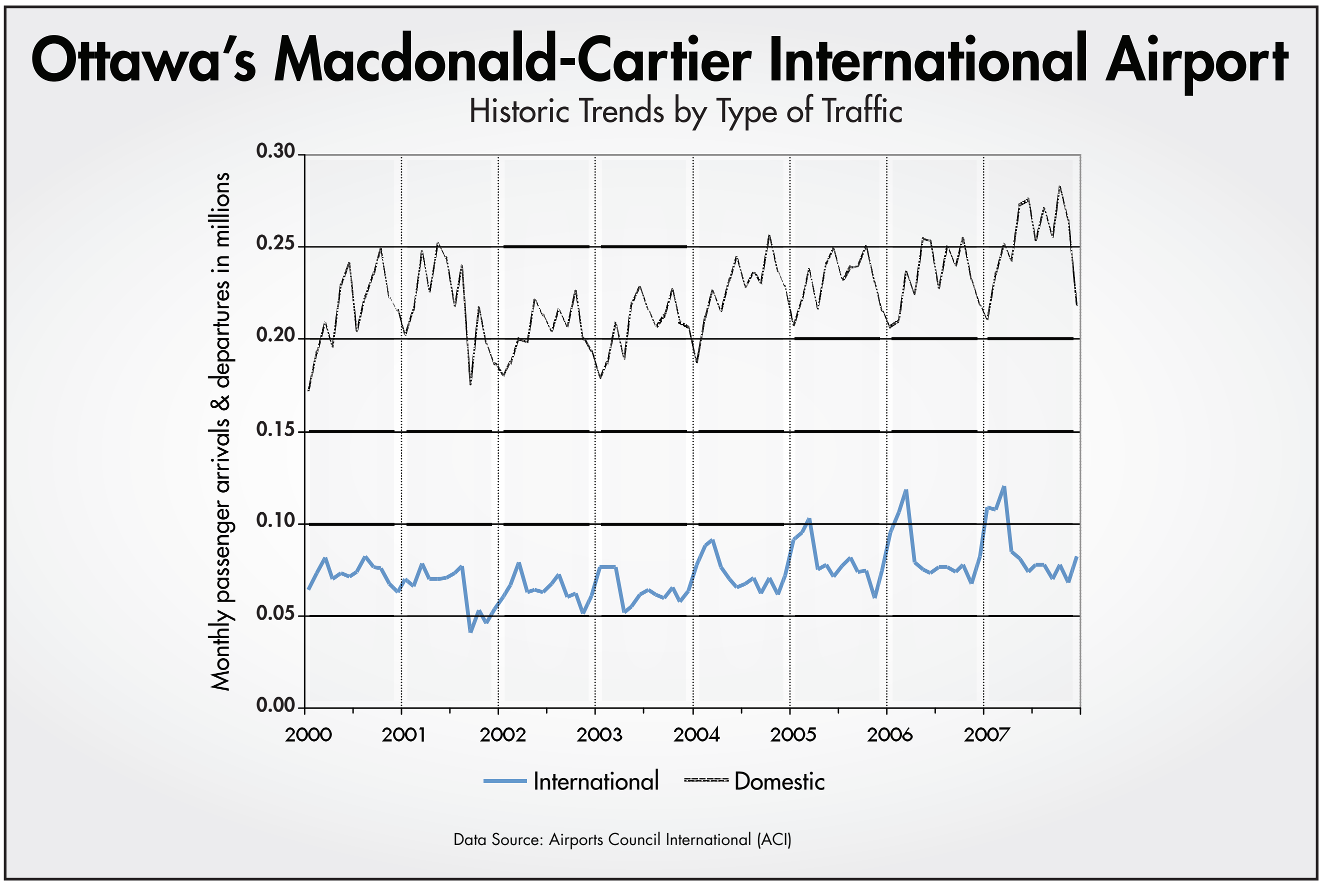


Exhibit 34:

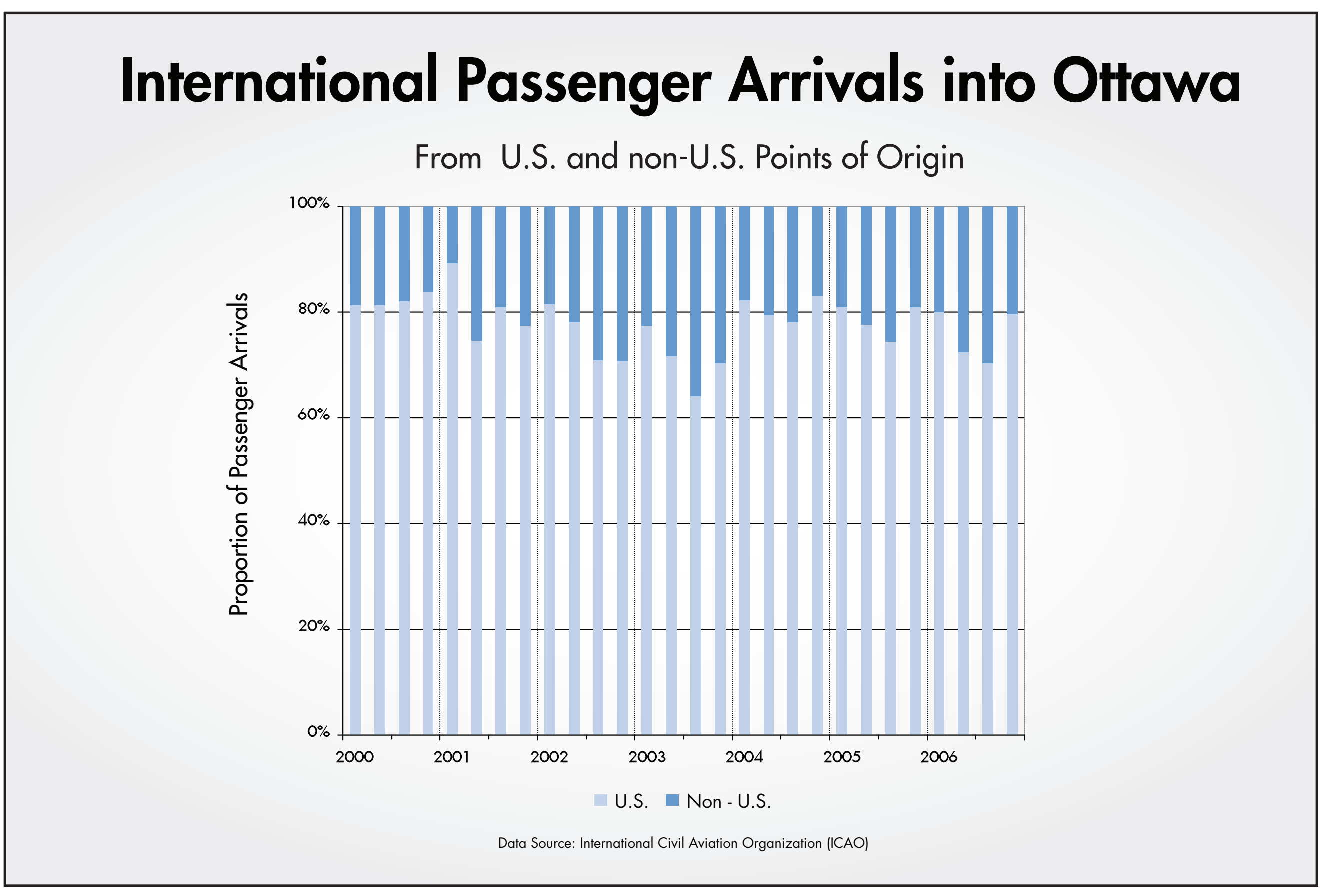


Exhibit 35: Web Map

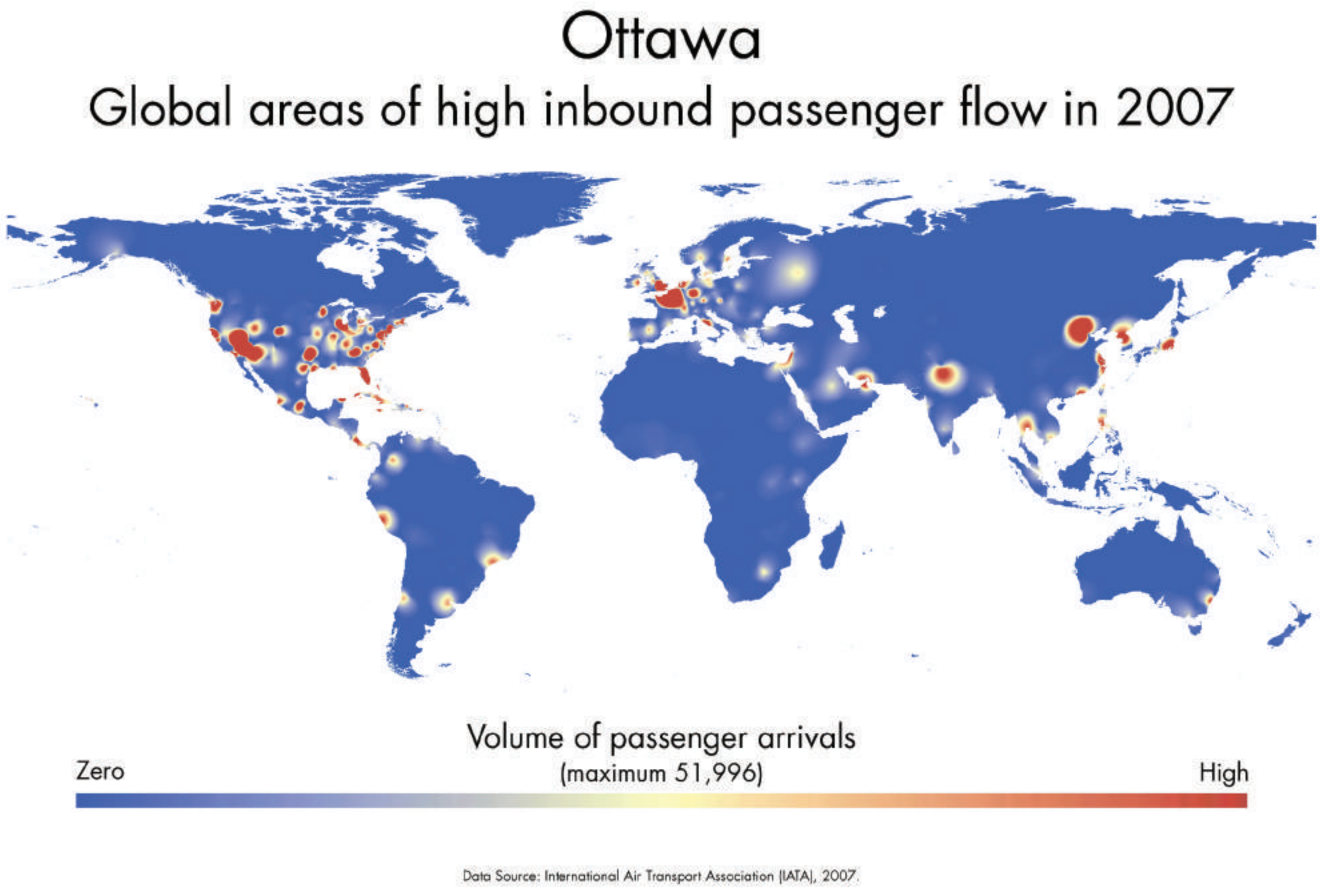


Exhibit 36:

Ottawa - Volume of International Passenger Arrivals from Leading Global Points of Origin*				
City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Cancun	Mexico	8363	5.6%	5.6%
Beijing	China	8037	5.4%	11.1%
Tokyo	Japan	5184	3.5%	14.6%
Hong Kong	Hong Kong (sar) China	5093	3.4%	18.0%
Mexico City	Mexico	4889	3.3%	21.3%
Shanghai	China	4671	3.2%	24.5%
Beirut	Lebanon	3831	2.6%	27.1%
Dubai	United Arab Emirates	3716	2.5%	29.6%
San Juan	Puerto Rico	3440	2.3%	31.9%
Seoul	Korea, Republic of	3280	2.2%	34.1%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

international traffic originates in the United States. Exhibit 35 spatially depicts areas of the world where passengers most frequently originate when traveling to Ottawa as a heat-map. Exhibit 36 shows the number of international passengers entering Ottawa from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

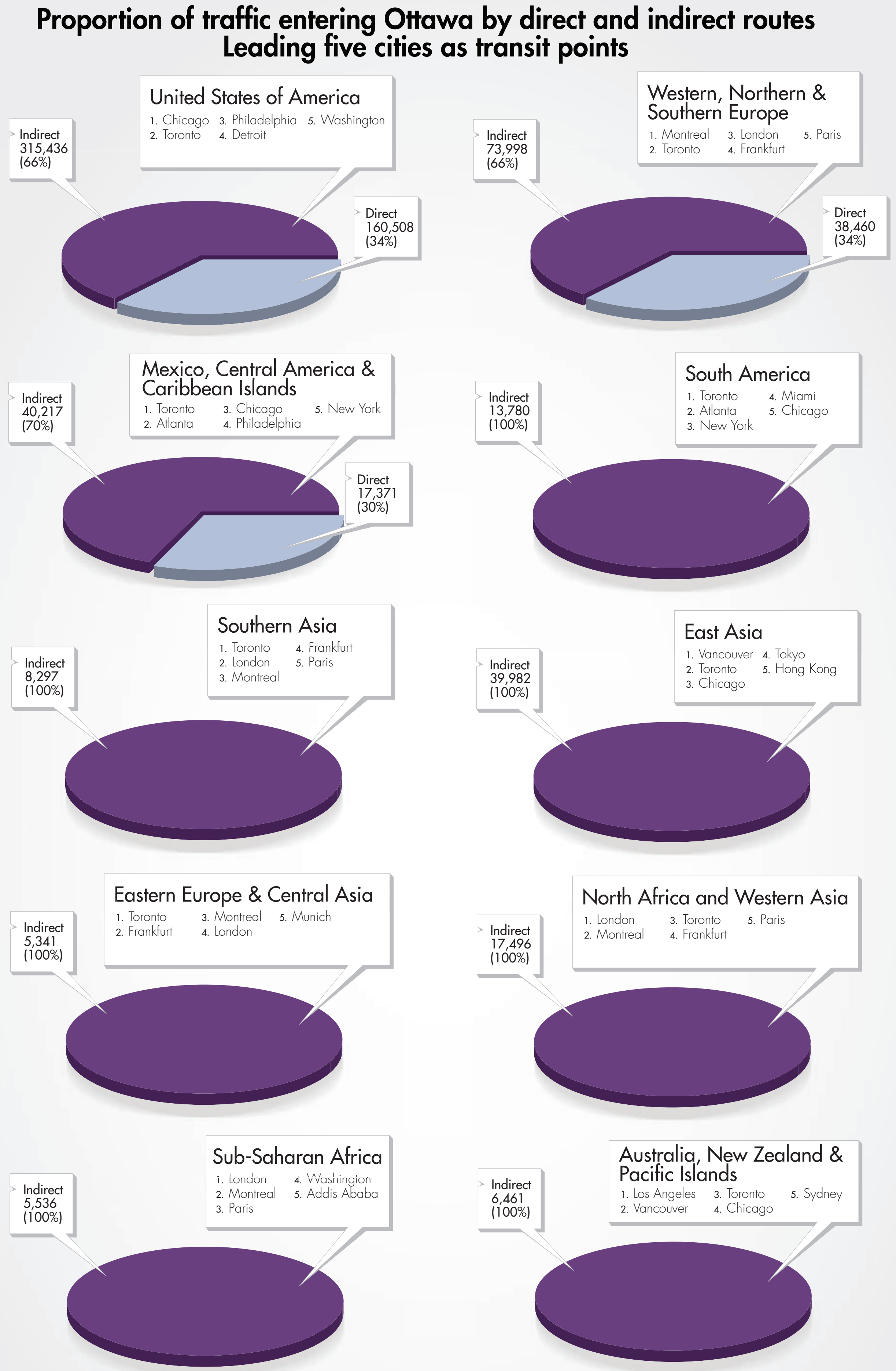
Exhibit 37 provides information on the preferred routes used by international passengers arriving in Ottawa when departing from different regions of the world. This information has been presented to identify all available frontiers for disease control. In the case of travelers arriving into Ottawa through non-stop flights, public health control measures are limited to the origin of the infectious disease threat and/or the domestic point of entry within Canada. For those traveling indirectly (i.e. requiring multiple flights), major transit points where flight connections are made represent another potential frontier for intervention. In these Exhibits, the top five international and/or domestic cities used by passengers as transit points en route to Ottawa are shown.

British Columbia

Exhibit 38 illustrates an important metric of global connectivity. All cities with international airports worldwide are shown in "degrees of separation" from British Columbia. In this analysis, "degrees of separation" are measured by the minimum number of flight connections required to land in any city across British Columbia. In network theory, directly connected nodes within a network tend to have the highest flows between them. With increasing degrees of separation (i.e. increasing number of steps) between nodes, network flows tend to decrease. In the case of British Columbia, the province is most vulnerable to infectious disease threats originating in cities shown in red (i.e. from which it has non-stop flights arriving), followed by cities in tan (i.e. from which at least one flight connection is required to enter British Columbia), and finally cities in green and blue (i.e. from which at least two and three flight connections respectively are required to enter British Columbia).

Exhibit 39 complements the findings of the previous Exhibit by illustrating areas of the world where passengers most frequently originate when traveling to British Columbia. It is important to note that hot-spots shown in this map reflect the true origins of international passengers in that all flight connections (if applicable) for each passenger trip have been accounted for. Since this type of map was designed as a visual aid, it should not be used to delineate the precise geographic boundaries of hot-spots. When interpreting this type of heat-map, readers should first examine the Volume of Passenger Arrivals bar to determine the maximum number of passengers represented by the map's hot-spots. Furthermore, different heat-maps should not be compared with one another, but rather interpreted independently. Complementing this heat-map is Exhibit 40, which shows the number of international passengers entering British Columbia from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Exhibit 37:

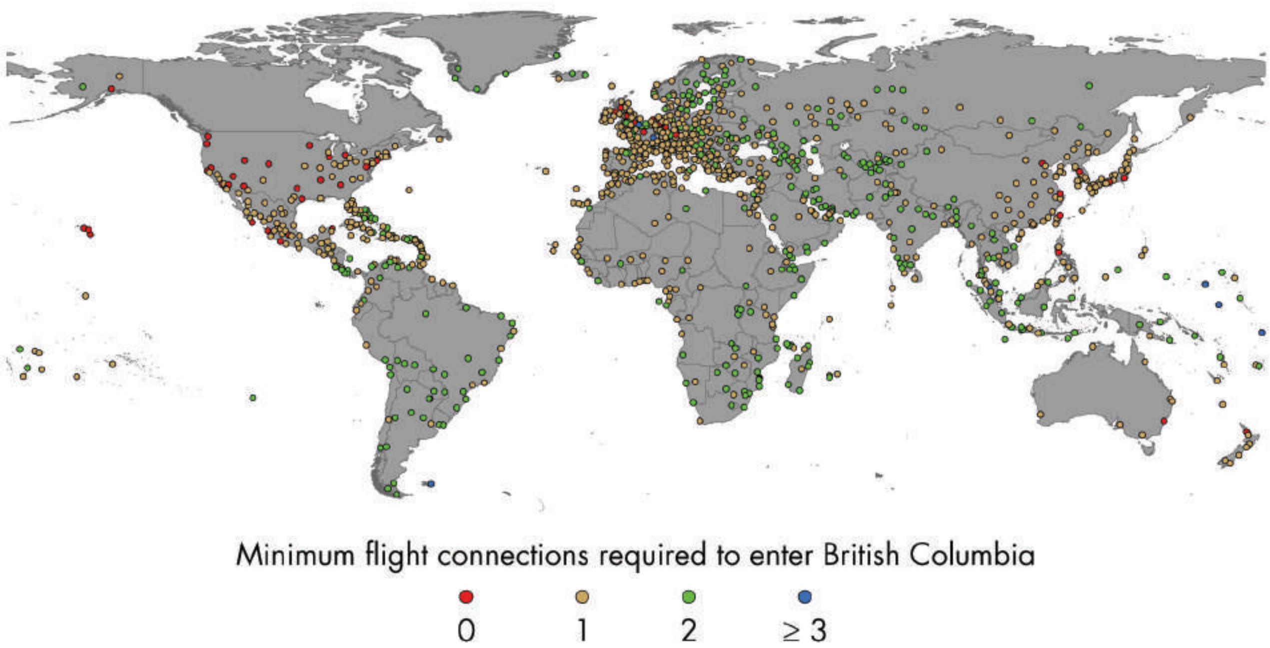


Passenger arrivals are categorized here as direct (no flight connections used) or indirect (at least one flight connection used). The five cities most frequently used as transit points along indirect routes are shown for each world region. Values in each pie graph represent the number of international passengers arriving into Toronto by world region in 2007.

Data Source: International Air Transport Association (IATA), 2007

Exhibit 38: Web Map

British Columbia
Global inbound connectivity in 2008



Data Source: Official Airline Guide (OAG), 2008.

Exhibit 39: Web Map

British Columbia
Global areas of high inbound passenger flow in 2007

Data Source: International Air Transport Association (IATA), 2007.

Exhibit 40:

British Columbia – Volume of International Passenger Arrivals from Leading Global Points of Origin*

City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Hong Kong	Hong Kong (sar) China	189986	15.3%	15.3%
Seoul	Korea, Republic of	115103	9.3%	24.6%
Tokyo	Japan	92503	7.5%	32.1%
Taipei	Chinese Taipei	75840	6.1%	38.2%
Delhi	India	60945	4.9%	43.1%
Beijing	China	57988	4.7%	47.8%
Shanghai	China	57658	4.7%	52.5%
Manila	Philippines	48258	3.9%	56.4%
Mexico City	Mexico	46784	3.8%	60.1%
Puerto Vallarta	Mexico	35378	2.9%	63.0%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 41:

Vancouver

Exhibit 41 illustrates the flow of international and domestic passengers entering Vancouver since the year 2000. Recurring seasonal patterns are observed with notable disruptions after the terrorist attacks of 9-11-2001 in the United States and during the 2003 worldwide outbreak of SARS. Complementing this figure is Exhibit 42 which quantifies the proportion of international traffic entering Vancouver from the United States and other non-U.S. points of origin over time. From this figure, it is apparent that slightly more than half of Vancouver's international traffic originates in the United States. Exhibit 43 spatially depicts areas of the world where passengers most frequently originate when traveling to Vancouver as a heat-map. Exhibit 44 shows the number of international passengers entering Vancouver from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Exhibit 45 provides information on the preferred routes used by international passengers arriving in Vancouver when departing from different regions of the world. This information has been presented to identify all available frontiers for disease control. In the case of travelers arriving into Vancouver through non-stop flights, public health control measures are limited to the origin of the infectious disease threat and/or the domestic point of entry within Canada. For those traveling indirectly (i.e. requiring multiple flights), major transit points where flight connections are made represent another potential frontier for intervention. In this Exhibit, the top five international and/or domestic cities used by passengers as transit points en route to Vancouver are shown.

Quebec

Exhibit 46 illustrates an important metric of global connectivity. All cities with international airports worldwide are shown in "degrees of separation" from Quebec. In this analysis, "degrees of separation" are measured by the minimum number of flight connections required to land in any city across Quebec. In network theory, directly connected nodes within a network tend to have the highest flows between them. With increasing degrees of separation (i.e. increasing number of steps) between nodes, network flows tend to decrease. In the case of Quebec, the province is most vulnerable to infectious disease threats originating in cities shown in red (i.e. from which it has non-stop flights arriving), followed by cities in tan (i.e. from which at least one flight connection is required to enter Quebec), and finally cities in green and blue (i.e. from which at least two and three flight connections respectively are required to enter Quebec).

Exhibit 47 complements the findings of previous Exhibit by illustrating areas of the world where passengers most frequently originate when traveling to Quebec. It is important to note that hot-spots shown in this map reflect the true origins of international passengers in that all flight connections (if applicable) for each passenger trip have been accounted for.

Since this type of map was designed as a visual aid, it should not be used to delineate

Exhibit 42:

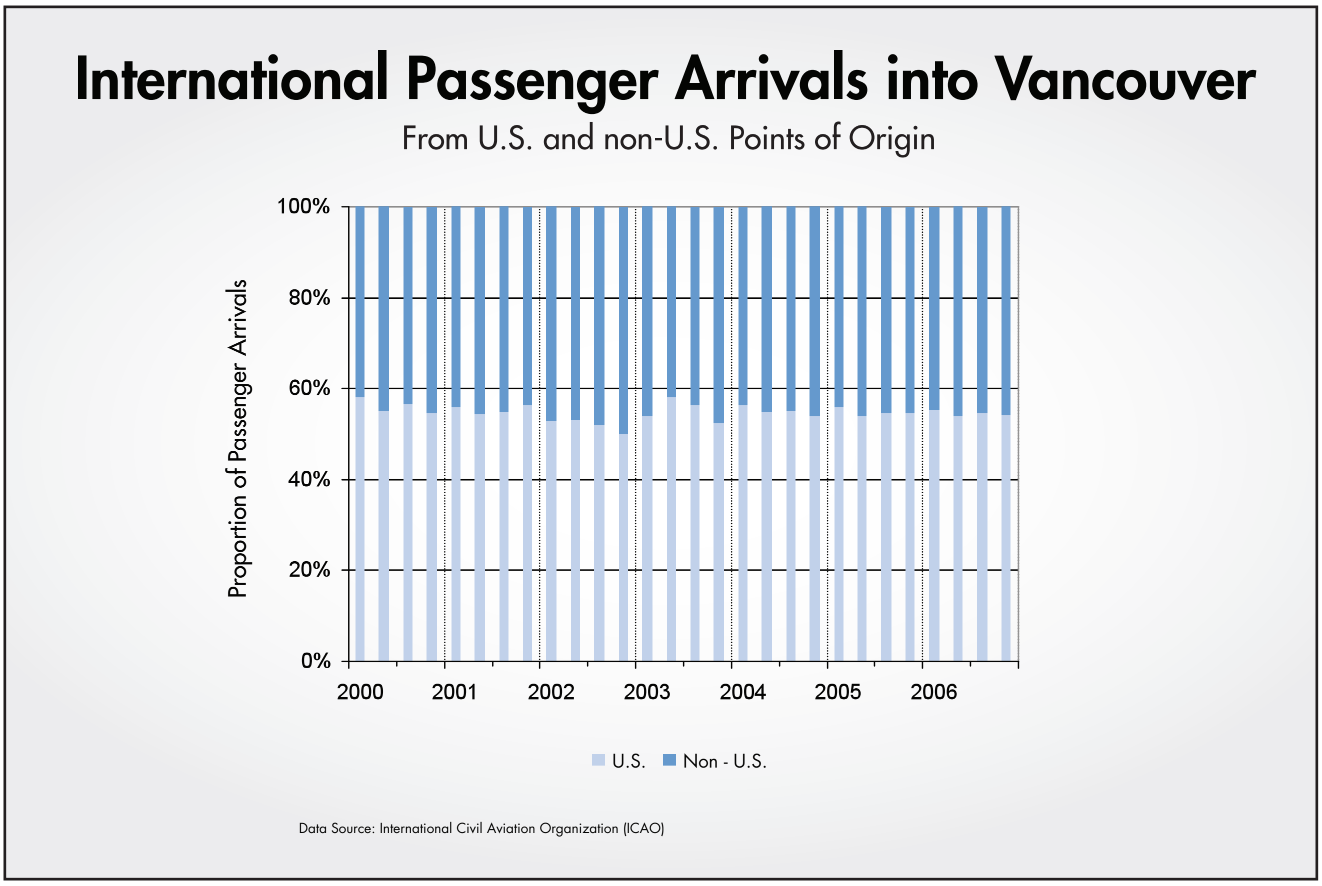


Exhibit 43: Web Map

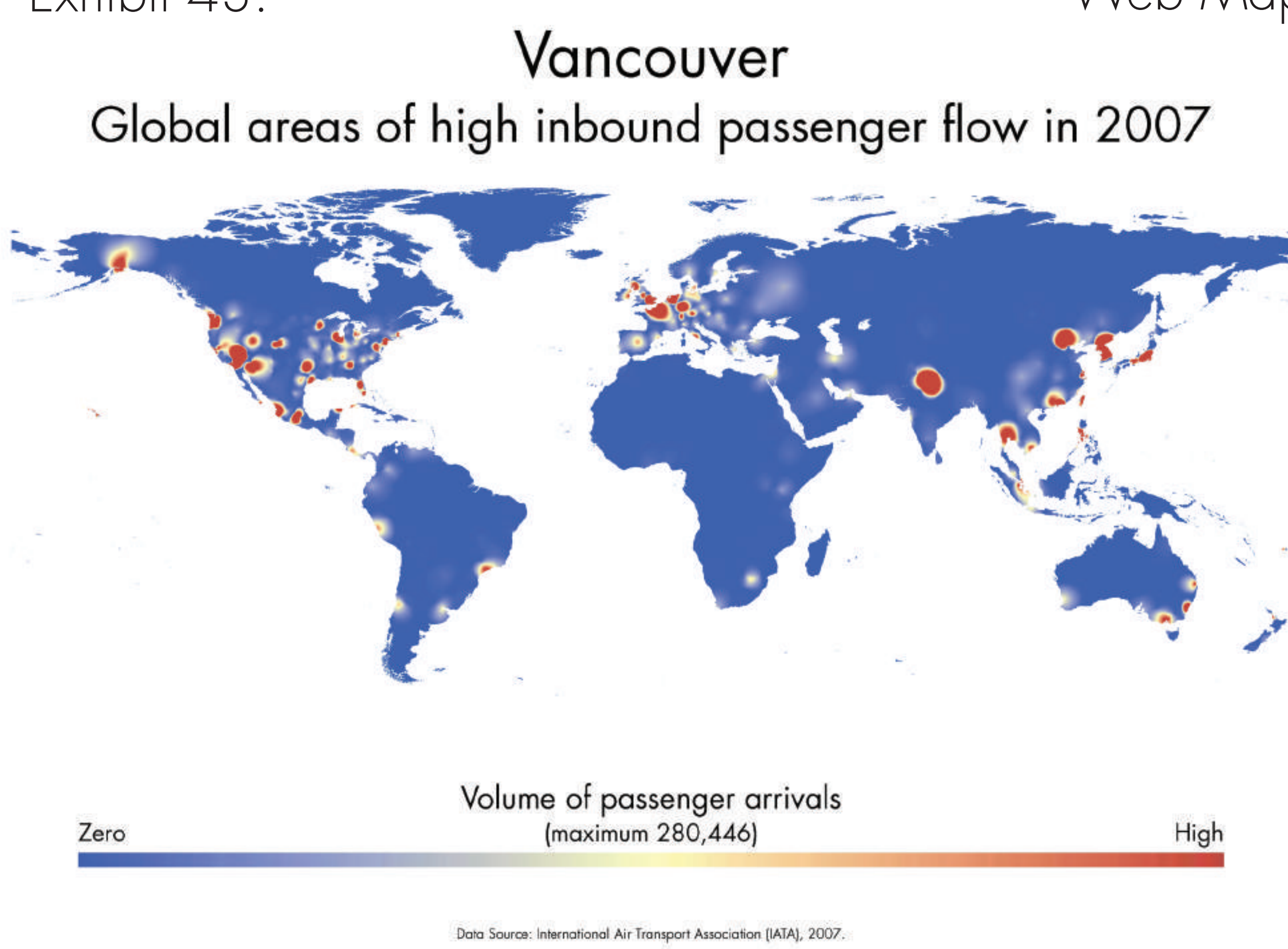


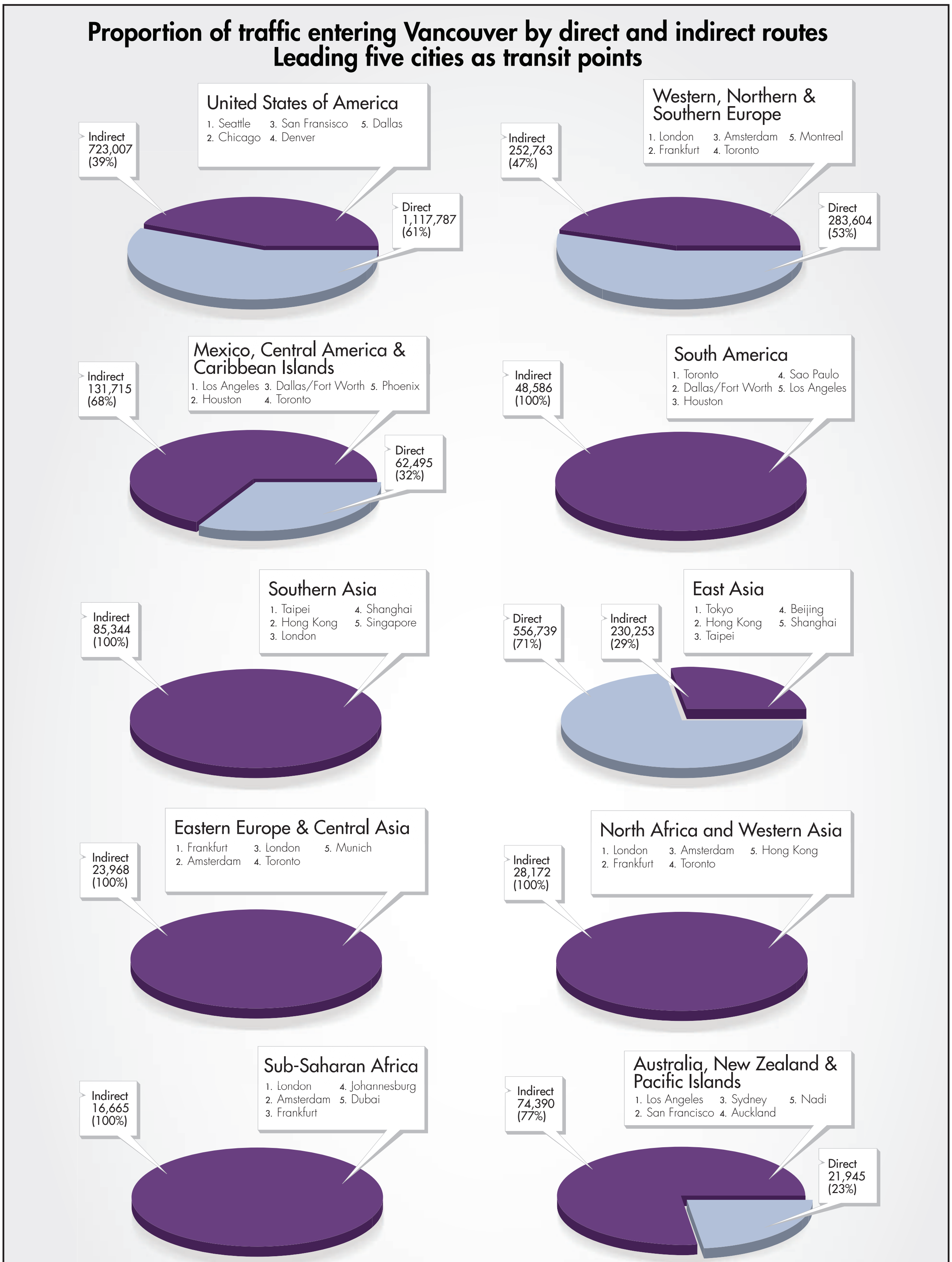
Exhibit 44:

Vancouver - Volume of International Passenger Arrivals from Leading Global Points of Origin*				
City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Hong Kong	Hong Kong (sar) China	187341	15.8%	15.8%
Seoul	Korea, Republic of	110286	9.3%	25.1%
Tokyo	Japan	86632	7.3%	32.5%
Taipei	Chinese Taipei	75039	6.3%	38.8%
Delhi	India	60491	5.1%	43.9%
Shanghai	China	56692	4.8%	48.7%
Beijing	China	56240	4.8%	53.4%
Manila	Philippines	47280	4.0%	57.4%
Mexico City	Mexico	45799	3.9%	61.3%
Puerto Vallarta	Mexico	29317	2.5%	63.8%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 45:



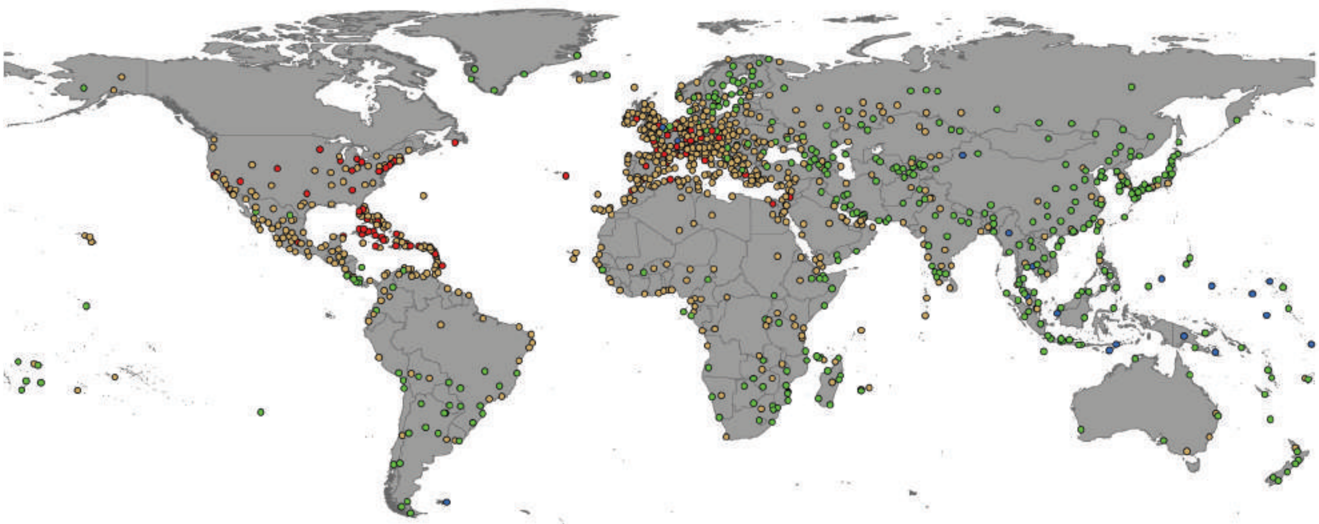
Passenger arrivals are categorized here as direct (no flight connections used) or indirect (at least one flight connection used). The five cities most frequently used as transit points along indirect routes are shown for each world region. Values in each pie graph represent the number of international passengers arriving into Toronto by world region in 2007.

Data Source: International Air Transport Association (IATA), 2007

Exhibit 46: Web Map

Quebec

Global inbound connectivity in 2008



Minimum flight connections required to enter Quebec

0 1 2 ≥ 3

Data Source: Official Airline Guide (OAG), 2008.

Exhibit 47: Web Map

Quebec

Global areas of high inbound passenger flow in 2007

Volume of passenger arrivals (maximum 284,551)

Zero — High

Data Source: International Air Transport Association (IATA), 2007.

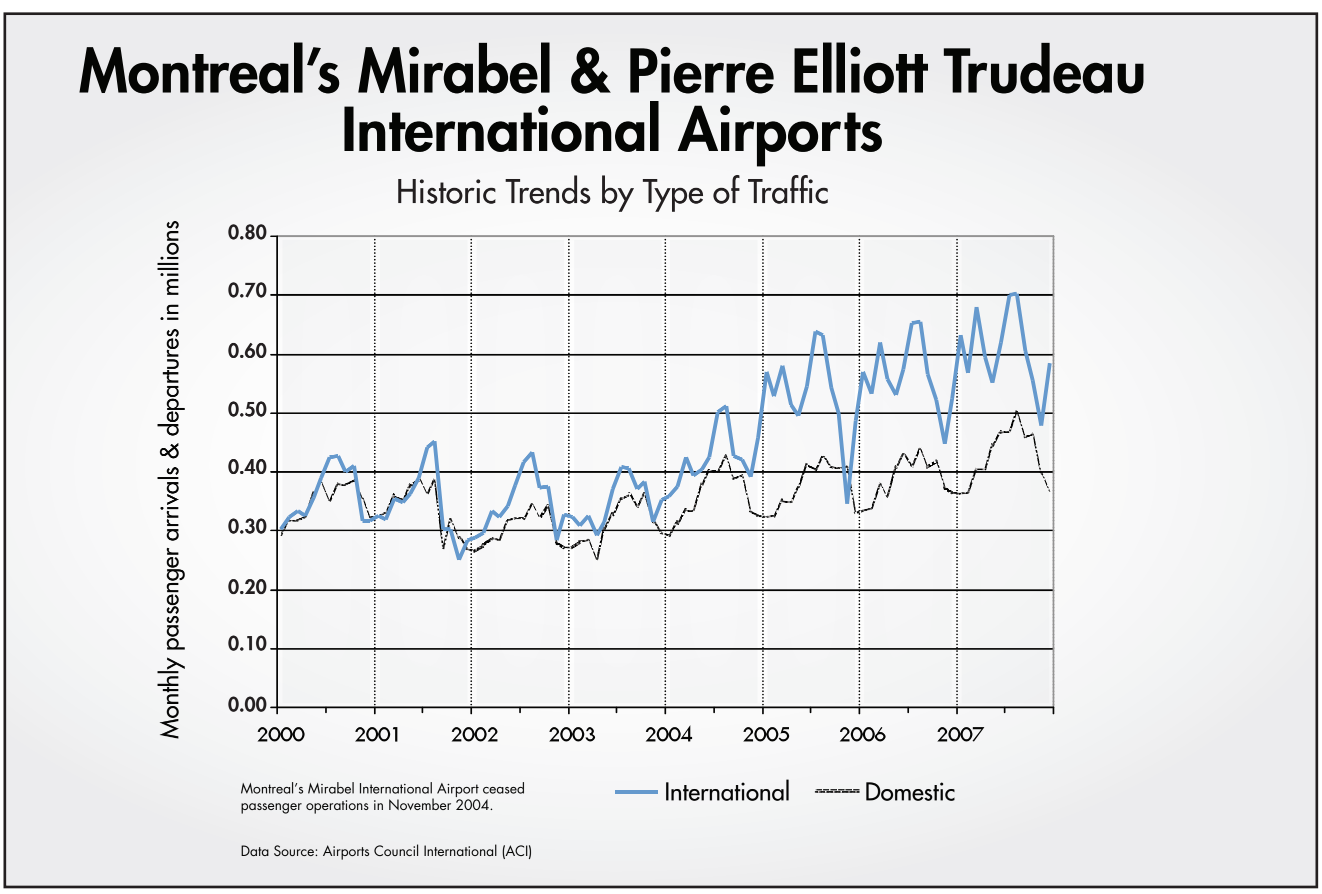
Exhibit 48:

Quebec - Volume of International Passenger Arrivals from Leading Global Points of Origin*				
City	**Country**	**Annual Volume of Passengers***	**% Annual Volume***	**Cumulative % Annual Volume***
Mexico City	Mexico	49291	5.7%	5.7%
Casablanca	Morocco	45308	5.3%	11.0%
Cancun	Mexico	30061	3.5%	14.5%
Beirut	Lebanon	23110	2.7%	17.2%
Hong Kong	Hong Kong (sar) China	21999	2.6%	19.8%
Tokyo	Japan	21533	2.5%	22.3%
Tunis	Tunisia	20328	2.4%	24.7%
Algiers	Algeria	19646	2.3%	27.0%
Varadero	Cuba	19125	2.2%	29.2%
Tel Aviv	Israel	18606	2.2%	31.4%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 49:



the precise geographic boundaries of hot-spots. When interpreting this type of heat-map, readers should first examine the Volume of Passenger Arrivals bar to determine the maximum number of passengers represented by the map's hot-spots. Furthermore, different heat-maps should not be compared with one another, but rather interpreted independently. Complementing this heat map is Exhibit 48, which shows the number of international passengers entering Quebec from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Montreal

Exhibit 49 illustrates the flow of international and domestic passengers entering Montreal since the year 2000. Recurring seasonal patterns are observed with notable disruptions after the terrorist attacks of 9-11-2001 in the United States and during the 2003 worldwide outbreak of SARS. Of note, the pattern of flow in Montreal changed significantly in late 2004 when Mirabel International Airport ceased passenger operations, leaving Trudeau as the sole international airport in the city. Complementing this figure is Exhibit 50 which quantifies the proportion of international traffic entering Montreal from the United States and other non-U.S. points of origin over time. From this figure, it is apparent that just over half of Montreal's international traffic originates in the United States. Exhibit 51 spatially depicts areas of the world where passengers most frequently originate when traveling to Montreal as a heat-map. Exhibit 52 shows the number of international passengers entering Montreal from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Exhibit 53 provides information on the preferred routes used by international passengers arriving in Montreal when departing from different regions of the world. This information has been presented to identify all available frontiers for disease control. In the case of travelers arriving into Montreal through non-stop flights, public health control measures are limited to the origin of the infectious disease threat and/or the domestic point of entry within Canada. For those traveling indirectly (i.e. requiring multiple flights), major transit points where flight connections are made represent another potential frontier for intervention. In this Exhibit, the top five international and/or domestic cities used by passengers as transit points en route to Montreal are shown.

Alberta

Exhibit 54 illustrates an important metric of global connectivity. All cities with international airports worldwide are shown in "degrees of separation" from Alberta. In this analysis, "degrees of separation" are measured by the minimum number of flight connections required to land in any city across Alberta. In network theory, directly connected nodes within a network tend to have the highest flows between them. With increasing degrees of separation (i.e. increasing number of steps) between nodes, network flows tend to decrease. In the case of Alberta, the province is most vulnerable to infectious disease threats originating in cities shown in red (i.e.

Exhibit 50:

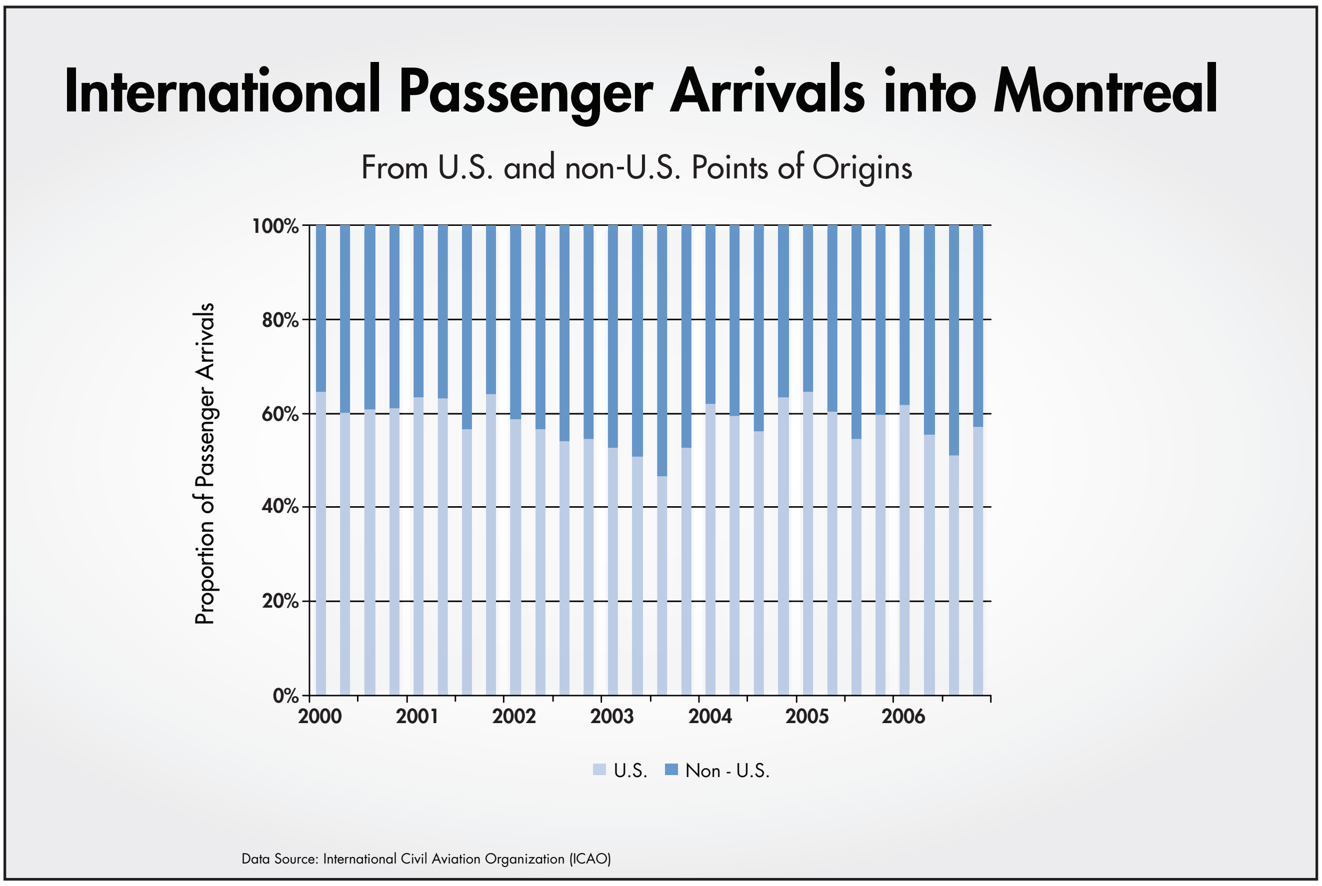


Exhibit 51: Web Map

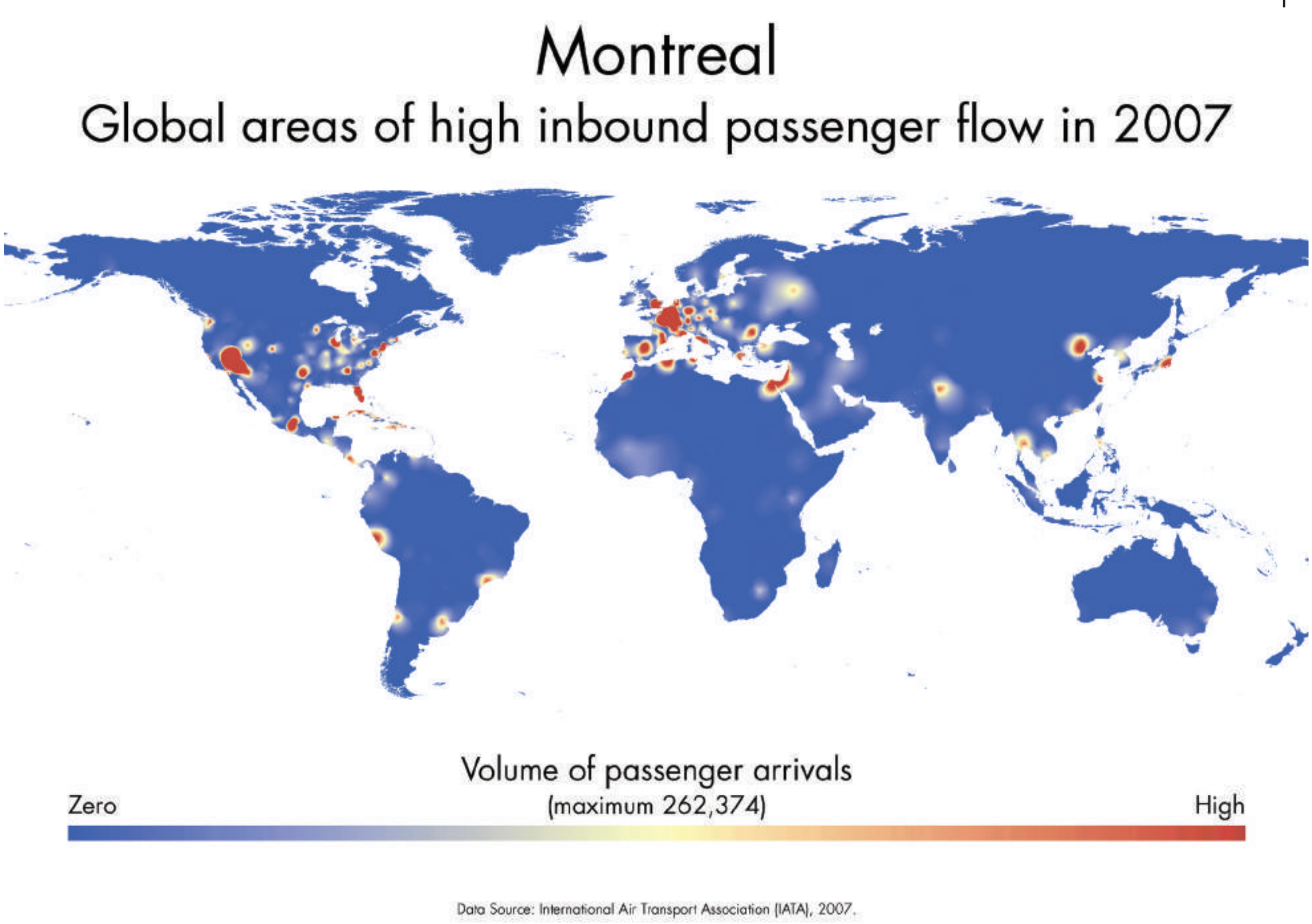


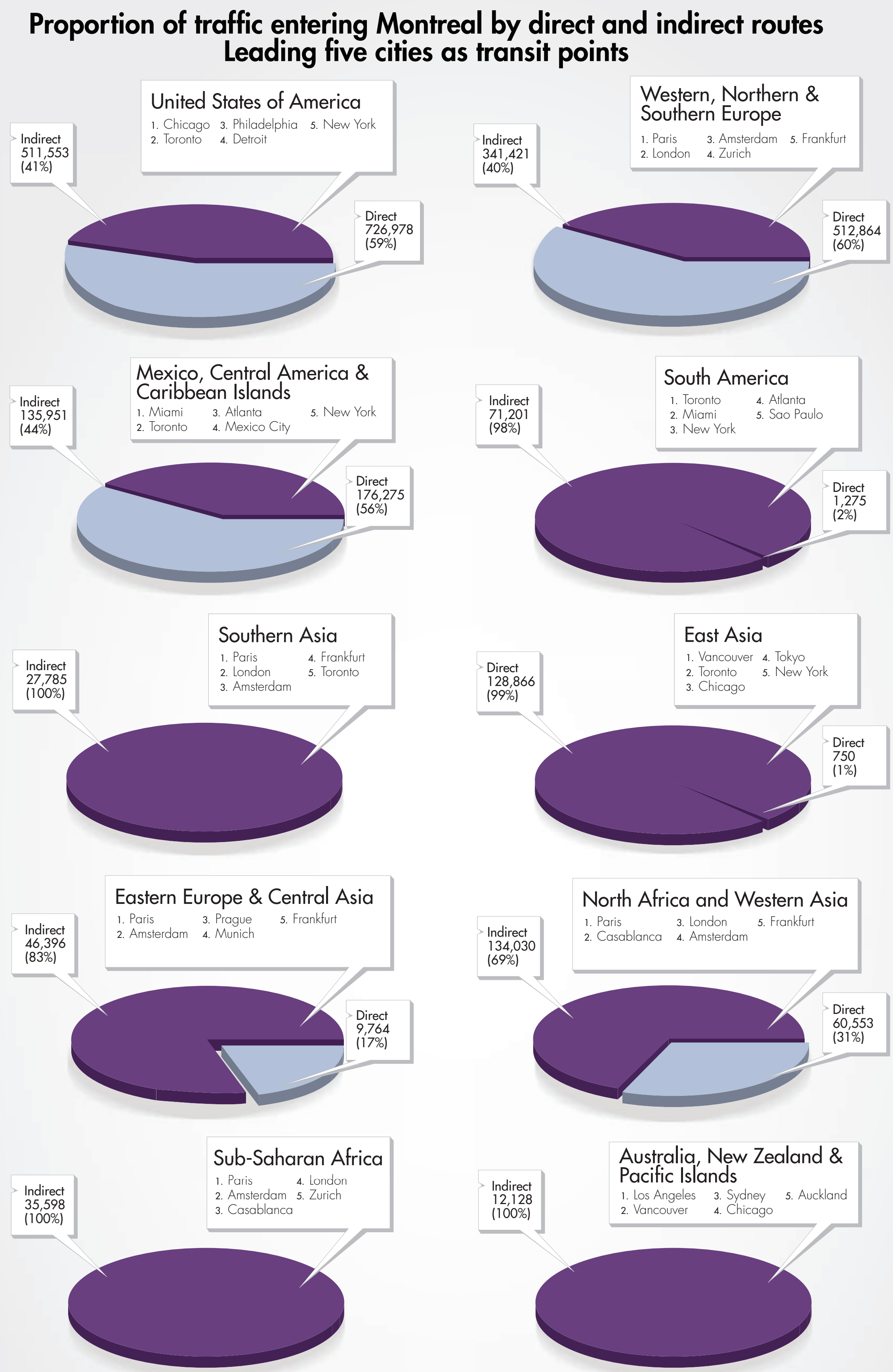
Exhibit 52:

Montreal - Volume of International Passenger Arrivals from Leading Global Points of Origin*				
City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Mexico City	Mexico	47185	5.7%	5.7%
Casablanca	Morocco	45274	5.5%	11.2%
Cancun	Mexico	28940	3.5%	14.7%
Beirut	Lebanon	23084	2.8%	17.4%
Hong Kong	Hong Kong (sar) China	20688	2.5%	19.9%
Tunis	Tunisia	19727	2.4%	22.3%
Algiers	Algeria	19608	2.4%	24.7%
Tokyo	Japan	19590	2.4%	27.1%
Varadero	Cuba	19093	2.3%	29.4%
Tel Aviv	Israel	18394	2.2%	31.6%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 53:



Passenger arrivals are categorized here as direct (no flight connections used) or indirect (at least one flight connection used). The five cities most frequently used as transit points along indirect routes are shown for each world region. Values in each pie graph represent the number of international passengers arriving into Toronto by world region in 2007.

Data Source: International Air Transport Association (IATA), 2007

Exhibit 54: Web Map

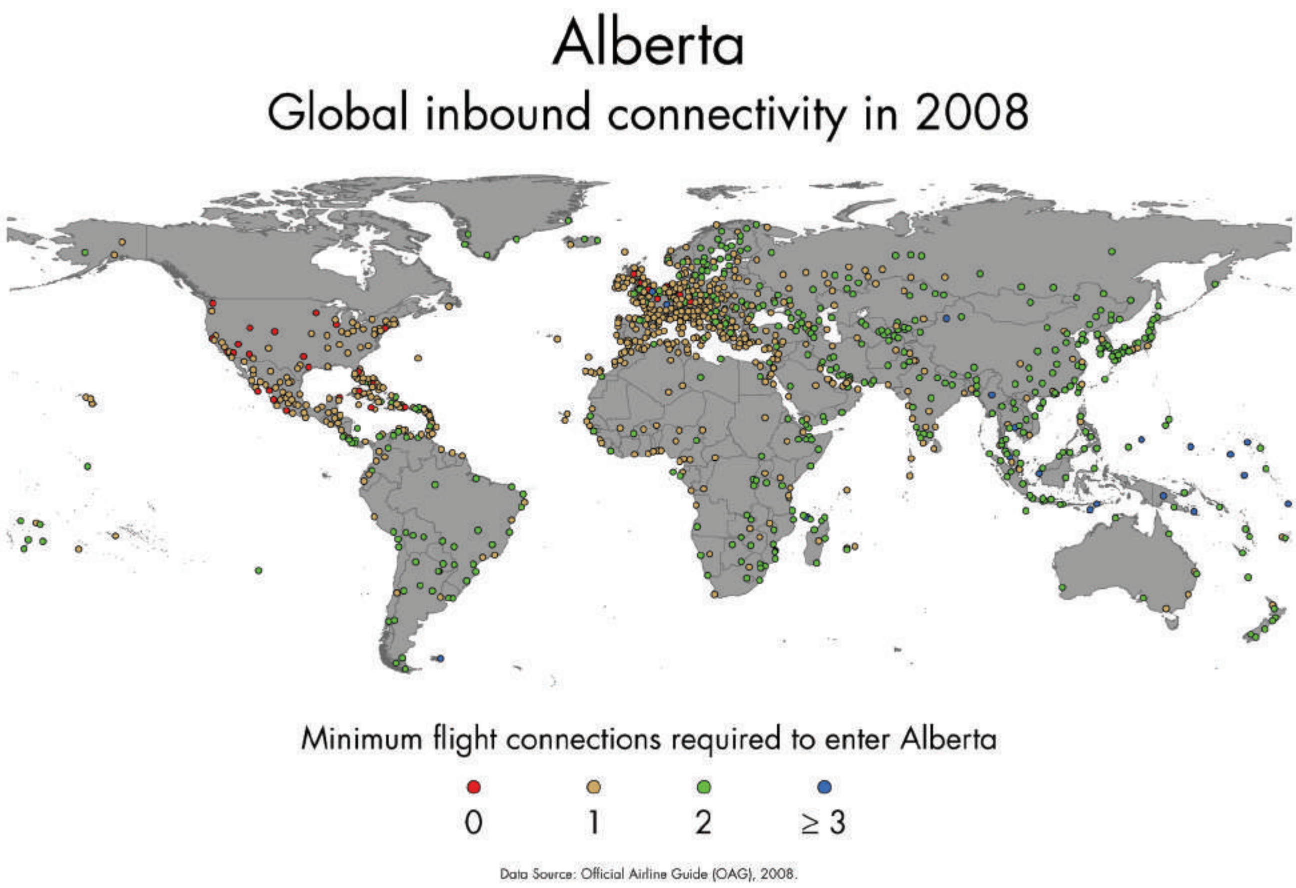
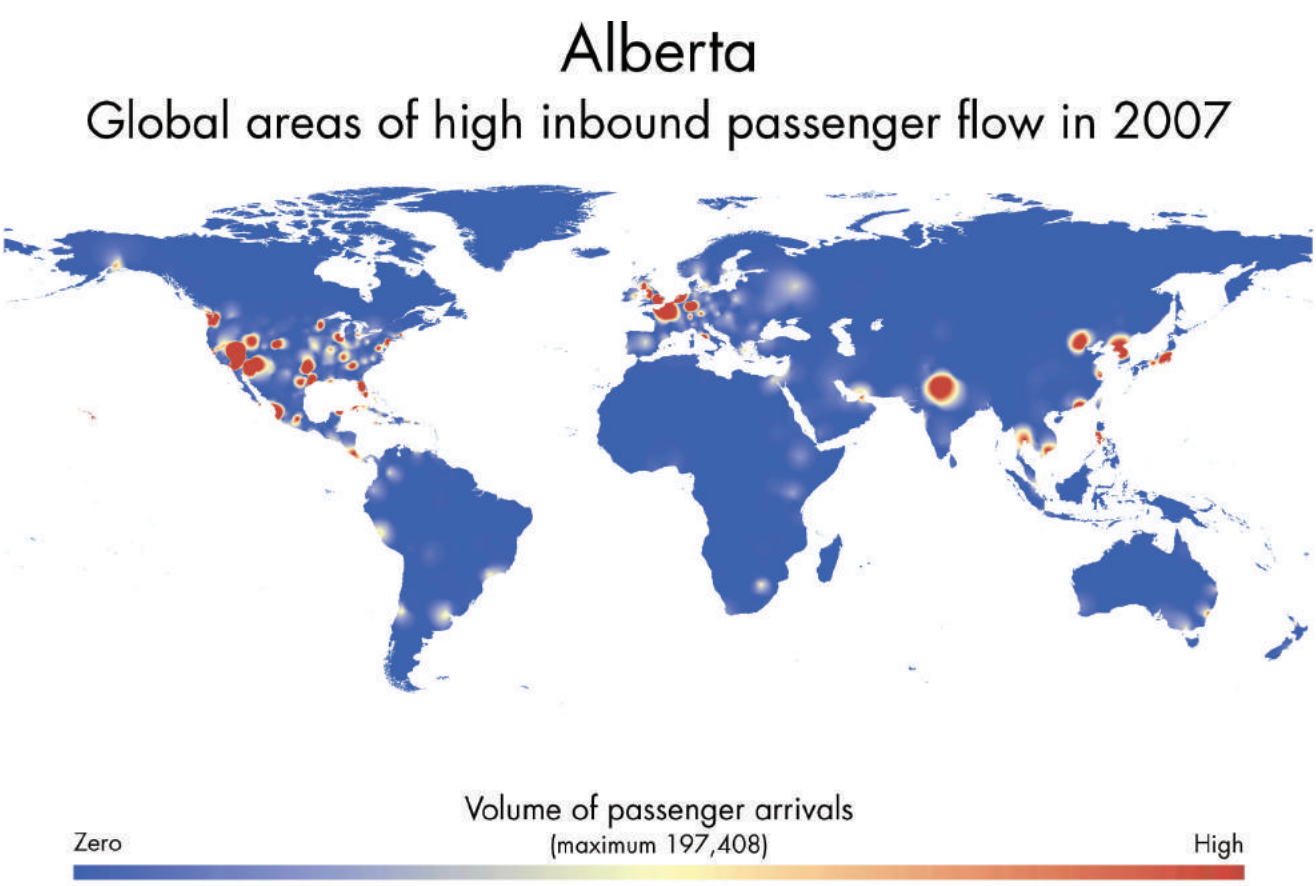


Exhibit 55: Web Map



from which it has non-stop flights arriving), followed by cities in tan (i.e. from which at least one flight connection is required to enter Alberta), and finally cities in green and blue (i.e. from which at least two and three flight connections respectively are required to enter Alberta).

Exhibit 55 complements the findings of the previous Exhibit by illustrating areas of the world where passengers most frequently originate when traveling to Alberta. It is important to note that hot-spots shown in this map reflect the true origins of international passengers in that all flight connections (if applicable) for each passenger trip have been accounted for. Since this type of map was designed as a visual aid, it should not be used to delineate the precise geographic boundaries of hot-spots. When interpreting this type of heat-map, readers should first examine the Volume of Passenger Arrivals bar to determine the maximum number of passengers represented by the map's hot-spots. Furthermore, different heat-maps should not be compared with one another, but rather interpreted independently. Complementing this heat map is Exhibit 56, which shows the number of international passengers entering Alberta from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Calgary

Exhibit 57 illustrates the flow of international and domestic passengers entering Calgary since the year 2001. Recurring seasonal patterns are observed with slight disruptions after the terrorist attacks of 9-11-2001 in the United States and during the 2003 worldwide outbreak of SARS. Complementing this figure is Exhibit 58 which quantifies the proportion of international traffic entering Calgary from the United States and other non-U.S. points of origin over time. From this figure, it is apparent that nearly eighty percent of Calgary's international traffic originates in the United States. Exhibit 59 spatially depicts areas of the world where passengers most frequently originate when traveling to Calgary as a heat-map. Exhibit 60 shows the number of international passengers entering Calgary from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Exhibit 61 provides information on the preferred routes used by international passengers arriving in Calgary when departing from different regions of the world. This information has been presented to identify all available frontiers for disease control. In the case of travelers arriving into Calgary through non-stop flights, public health control measures are limited to the origin of the infectious disease threat and/or the domestic point of entry within Canada. For those traveling indirectly (i.e. requiring multiple flights), major transit points where flight connections are made represent another potential frontier for intervention. In this Exhibit, the top five international and/or domestic cities used by passengers as transit points en route to Calgary are shown.

Exhibit 56:

Alberta - Volume of International Passenger Arrivals from Leading Global Points of Origin*				
City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Cancun	Mexico	35011	6.7%	6.7%
Puerto Vallarta	Mexico	33852	6.5%	13.2%
Hong Kong	Hong Kong (sar) China	28609	5.4%	18.6%
Tokyo	Japan	27461	5.3%	23.9%
Manila	Philippines	20955	4.0%	27.9%
Seoul	Korea, Republic of	18734	3.6%	31.5%
Delhi	India	17410	3.3%	34.8%
Beijing	China	17162	3.3%	38.1%
Mexico City	Mexico	11232	2.2%	40.2%
Osaka	Japan	10230	2.0%	42.2%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 57:

Exhibit 58:

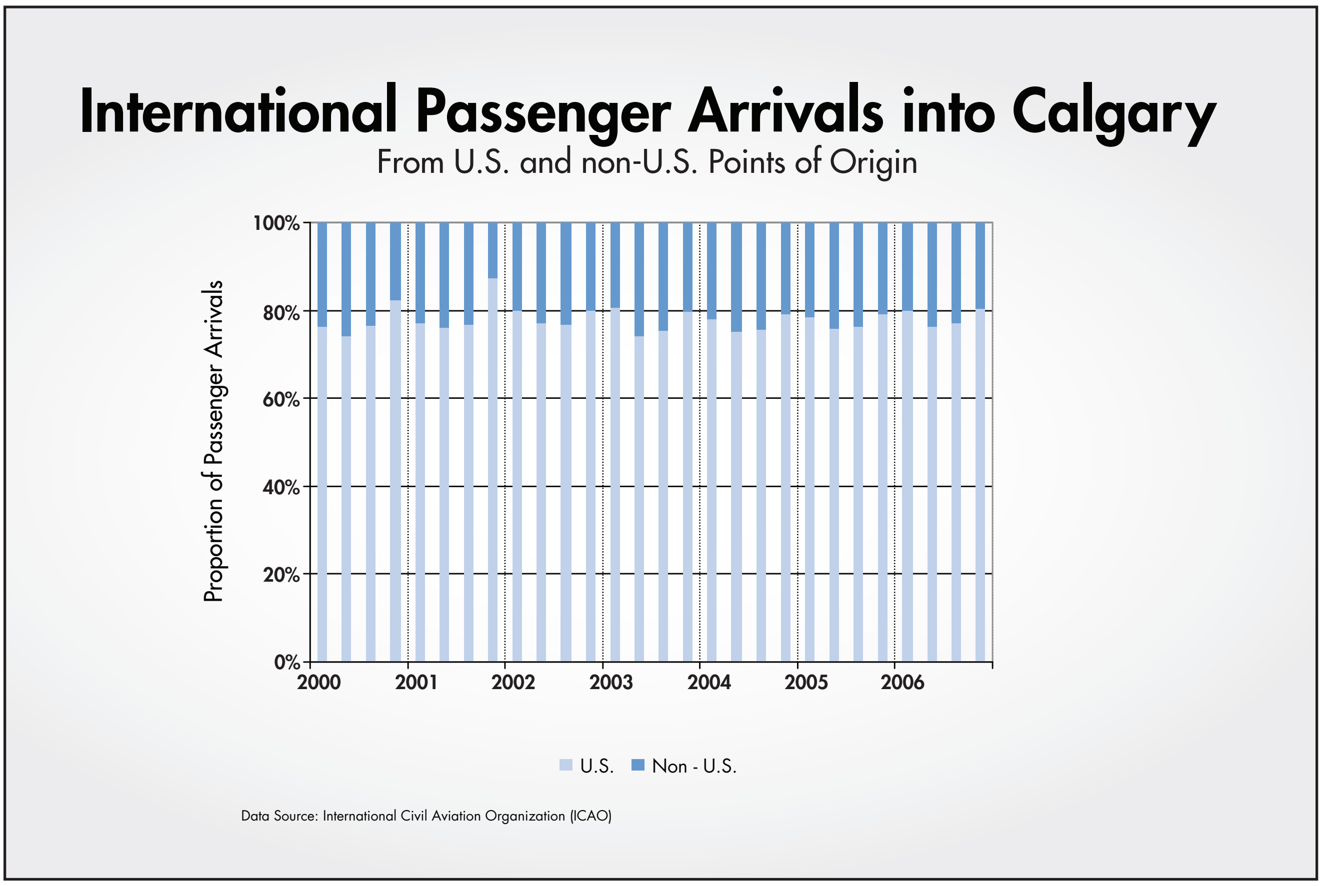


Exhibit 59:

Web Map

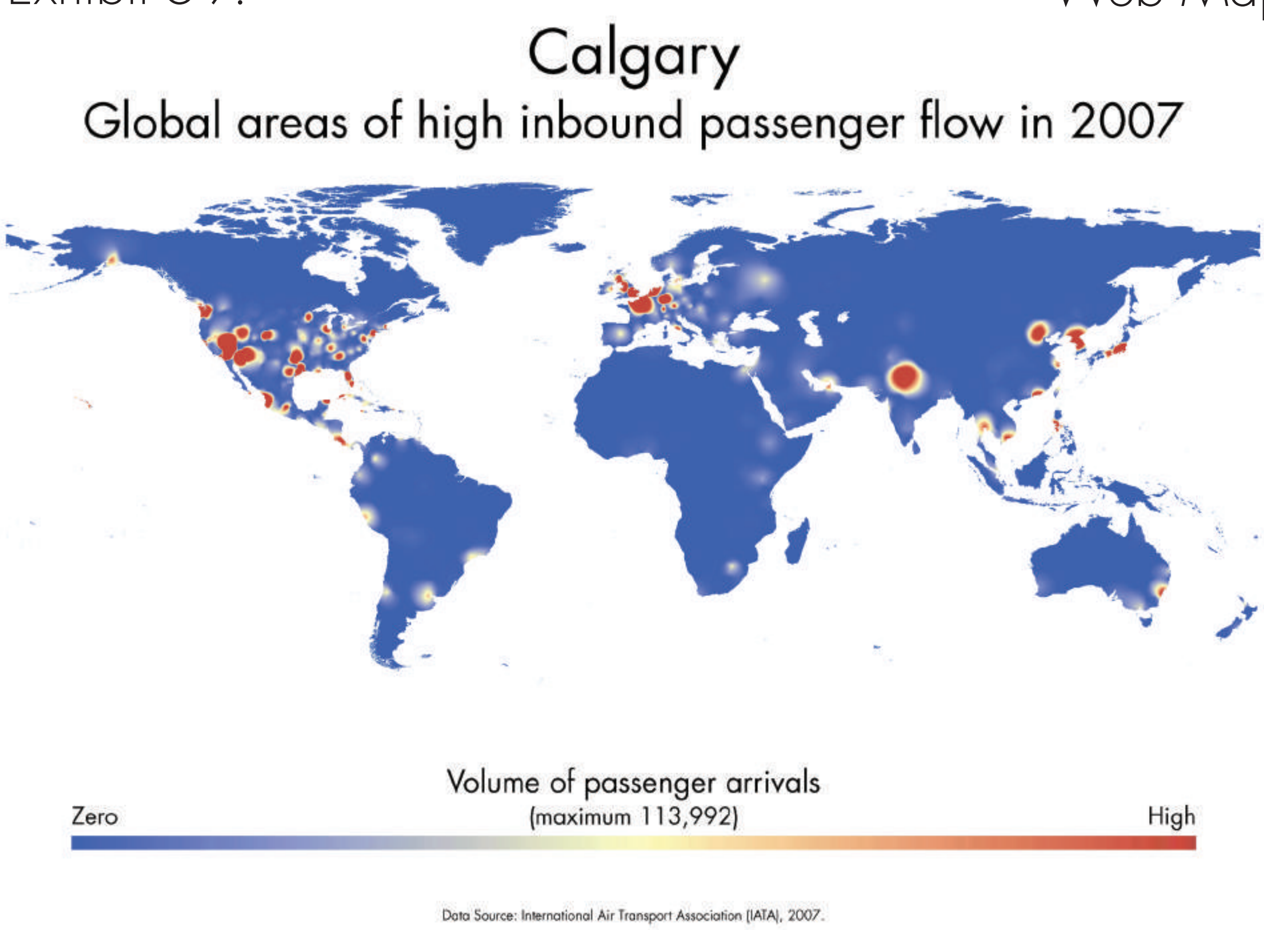


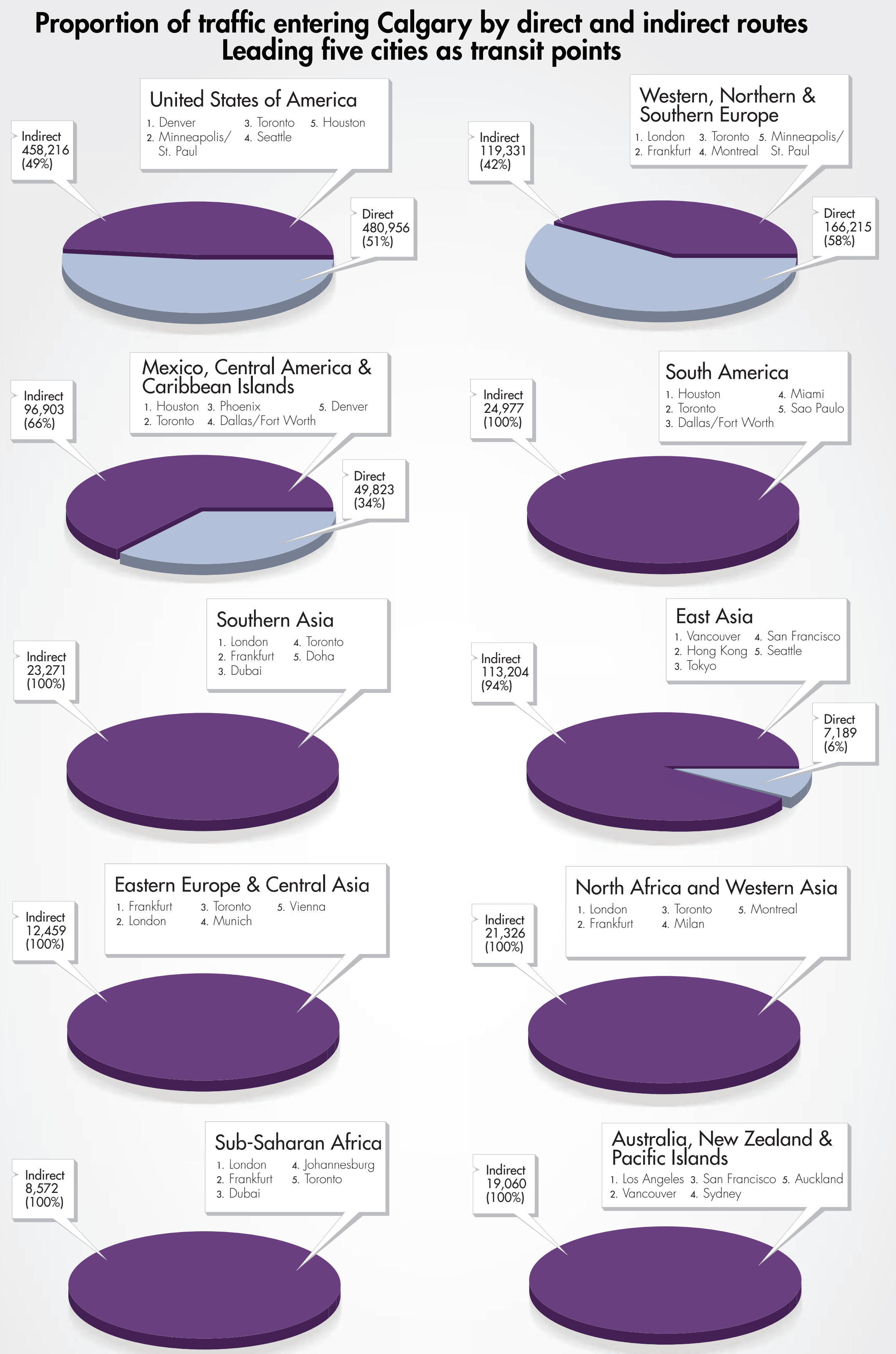
Exhibit 60:

Calgary - Volume of International Passenger Arrivals from Leading Global Points of Origin*				
City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Puerto Vallarta	Mexico	23183	6.5%	6.5%
Tokyo	Japan	22903	6.4%	12.9%
Cancun	Mexico	21901	6.1%	19.0%
Hong Kong	Hong Kong (sar) China	17445	4.9%	23.9%
Seoul	Korea, Republic of	14352	4.0%	27.9%
Manila	Philippines	11973	3.3%	31.2%
Delhi	India	11506	3.2%	34.5%
Beijing	China	10859	3.0%	37.5%
Osaka	Japan	9017	2.5%	40.0%
Mexico City	Mexico	8243	2.3%	42.3%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 61:



Passenger arrivals are categorized here as direct (no flight connections used) or indirect (at least one flight connection used). The five cities most frequently used as transit points along indirect routes are shown for each world region. Values in each pie graph represent the number of international passengers arriving into Toronto by world region in 2007.

Data Source: International Air Transport Association (IATA), 2007

Atlantic Canada: Nova Scotia, New Brunswick, Prince Edward Island & Newfoundland & Labrador

Exhibit 62 illustrates an important metric of global connectivity. All cities with international airports worldwide are shown in "degrees of separation" from Atlantic Canada. In this analysis, "degrees of separation" are measured by the minimum number of flight connections required to land in any city across Atlantic Canada. In network theory, directly connected nodes within a network tend to have the highest flows between them. With increasing degrees of separation (i.e. increasing number of steps) between nodes, network flows tend to decrease. In the case of Atlantic Canada, the region is most vulnerable to infectious disease threats originating in cities shown in red (i.e. from which it has non-stop flights arriving), followed by cities in tan (i.e. from which at least one flight connection is required to enter Atlantic Canada), and finally cities in green and blue (i.e. from which at least two and three flight connections respectively are required to enter Atlantic Canada).

Exhibit 63 complements the findings of the previous Exhibit by illustrating areas of the world where passengers most frequently originate when traveling to Atlantic Canada. It is important to note that hot-spots shown in this map reflect the true origins of international passengers in that all flight connections (if applicable) for each passenger trip have been accounted for. Since this type of map was designed as a visual aid, it should not be used to delineate the precise geographic boundaries of hot-spots. When interpreting this type of heat-map, readers should first examine the Volume of Passenger Arrivals bar to determine the maximum number of passengers represented by the map's hot-spots. Furthermore, different heat-maps should not be compared with one another, but rather interpreted independently. Complementing this heat map is Exhibit 64, which shows the number of international passengers entering Atlantic Canada from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

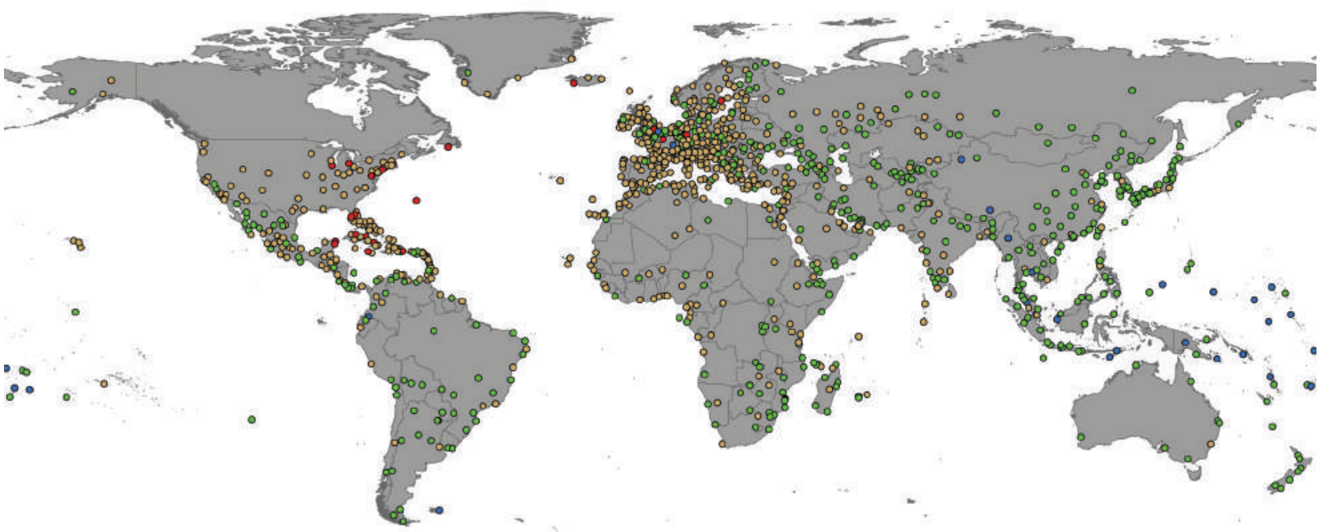
Halifax

Exhibit 65 illustrates the flow of international and domestic passengers entering Halifax since the year 2002. Recurring seasonal patterns are observed without noticeable disruption during the 2003 worldwide outbreak of SARS. Complementing this figure is Exhibit 66 which quantifies the proportion of international traffic entering Halifax from the United States and other non-U.S. points of origin over time. From this figure, it is apparent that more than sixty percent of Halifax's international traffic originates in the United States. Exhibit 67 spatially depicts areas of the world where passengers most frequently originate when traveling to Halifax as a heat-map. Exhibit 68 shows the number of international passengers entering Halifax from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Exhibit 69 provides information on the preferred routes used by international pas-

Exhibit 62: Web Map

Atlantic Canada
Global inbound connectivity in 2008



Minimum flight connections required to enter Atlantic Canada

0 1 2 ≥ 3

Data Source: Official Airline Guide (OAG), 2008.

Exhibit 63: Web Map

Atlantic Canada
Global areas of high inbound passenger flow in 2007

Volume of passenger arrivals
(maximum 47,401)

Zero High

Data Source: International Air Transport Association (IATA), 2007.

Exhibit 64:

Atlantic Canada - Volume of International Passenger Arrivals from Leading Global Points of Origin*				
City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Cancun	Mexico	6357	7.0%	7.0%
Puerto Plata	Dominican Republic	4325	4.8%	11.8%
Nassau	Bahamas	3543	3.9%	15.7%
Tokyo	Japan	3543	3.9%	19.6%
Seoul	Korea, Republic of	3474	3.8%	23.5%
Varadero	Cuba	3452	3.8%	27.3%
Beijing	China	3144	3.5%	30.7%
San Juan	Puerto Rico	3044	3.4%	34.1%
Dubai	United Arab Emirates	2892	3.2%	37.3%
Punta Cana	Dominican Republic	2728	3.0%	40.3%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 65:

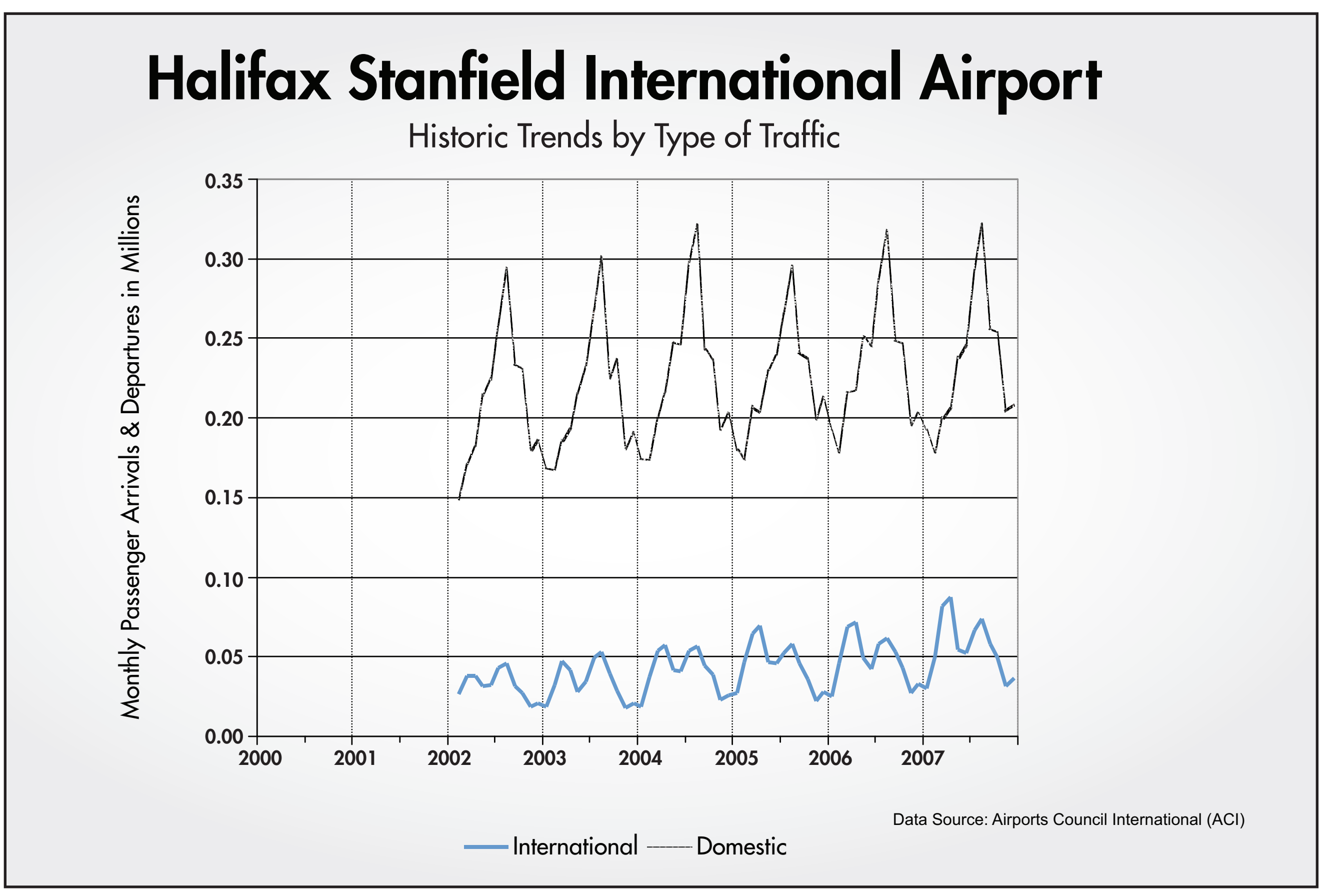


Exhibit 66:

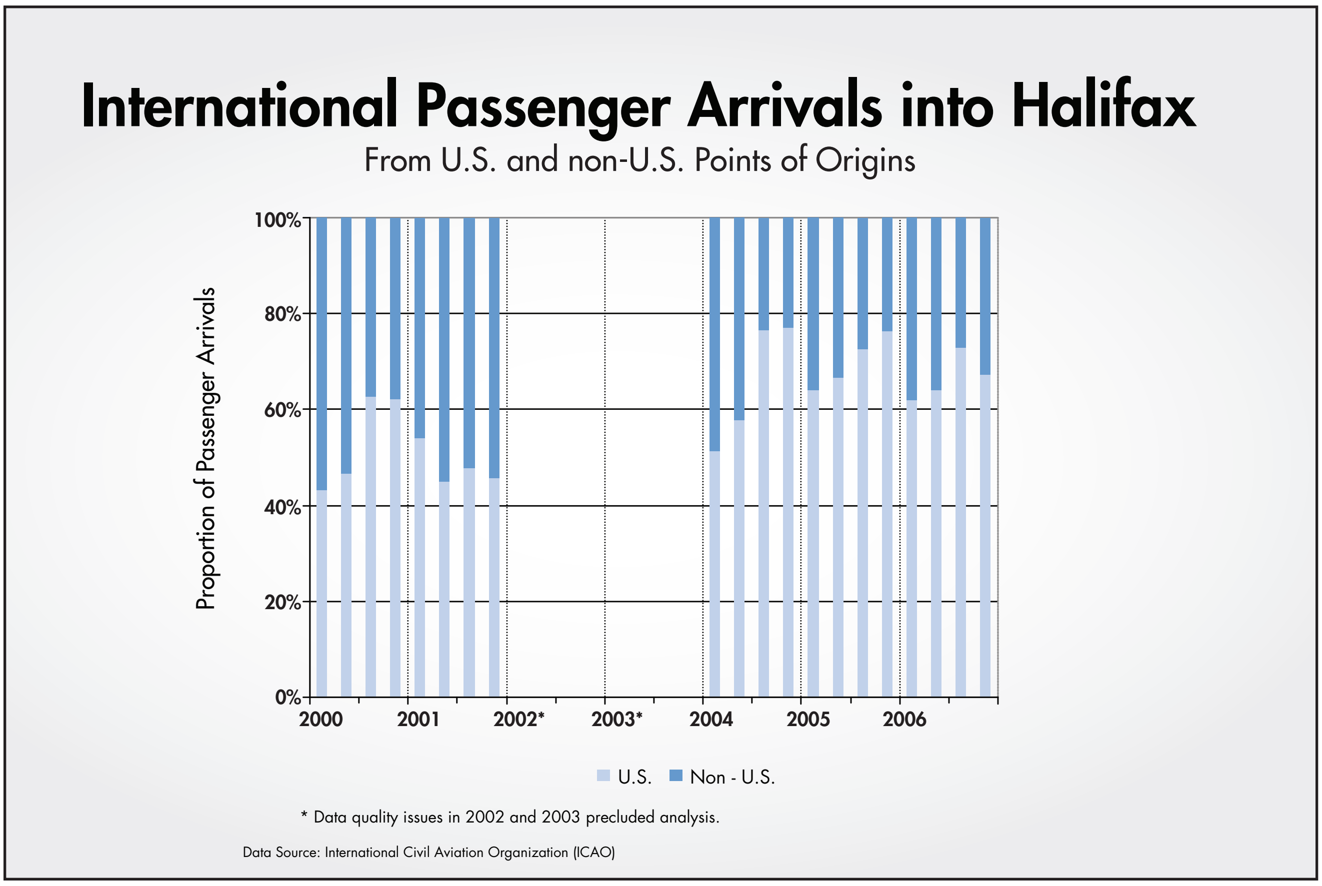


Exhibit 67:

Web Map

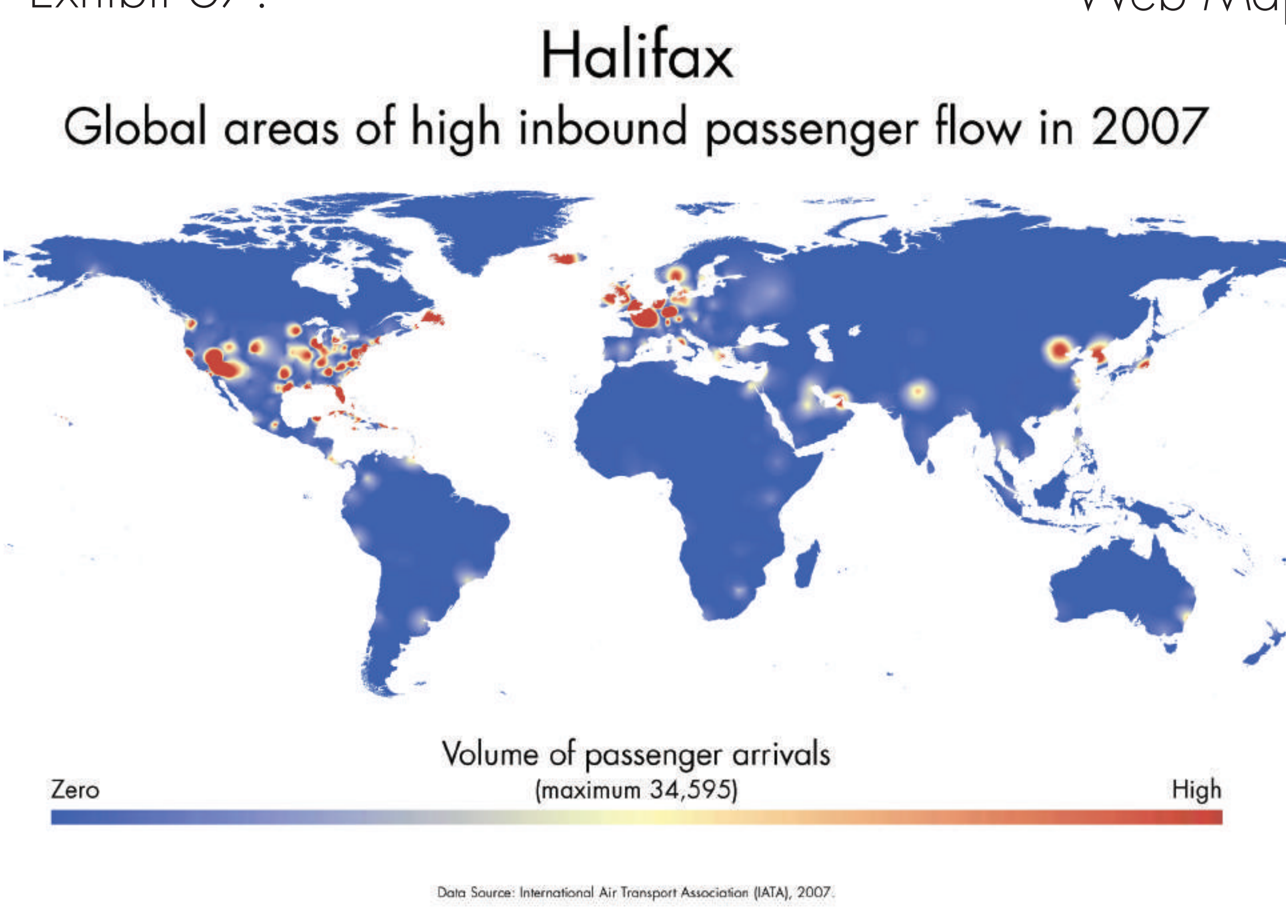


Exhibit 68:

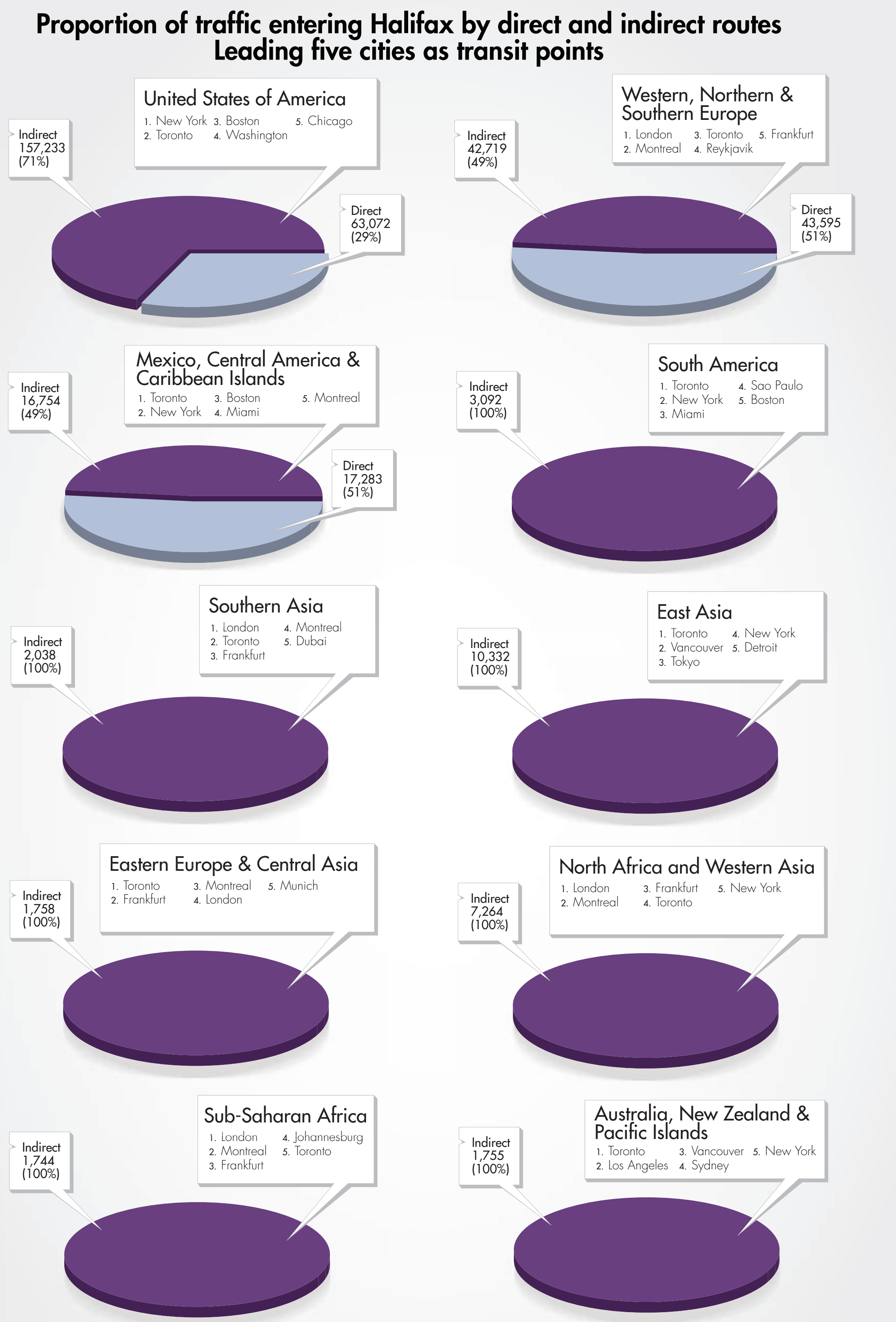
Halifax - Volume of International Passenger Arrivals from Leading Global Points of Origin*

City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Cancun	Mexico	4367	7.2%	7.2%
Puerto Plata	Dominican Republic	3509	5.8%	13.1%
Varadero	Cuba	3236	5.4%	18.4%
Cayo Coco	Cuba	2426	4.0%	22.5%
Punta Cana	Dominican Republic	2409	4.0%	26.5%
San Juan	Puerto Rico	2007	3.3%	29.8%
Nassau	Bahamas	1843	3.1%	32.8%
Tokyo	Japan	1823	3.0%	35.9%
Seoul	Korea, Republic of	1789	3.0%	38.8%
Dubai	United Arab Emirates	1716	2.8%	41.7%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 69:



Passenger arrivals are categorized here as direct (no flight connections used) or indirect (at least one flight connection used). The five cities most frequently used as transit points along indirect routes are shown for each world region.Values in each pie graph represent the number of international passengers arriving into Toronto by world region in 2007.

Data Source: International Air Transport Association (IATA), 2007

sengers arriving in Halifax when departing from different regions of the world. This information has been presented to identify all available frontiers for disease control. In the case of travelers arriving into Halifax through non-stop flights, public health control measures are limited to the origin of the infectious disease threat and/or the domestic point of entry within Canada. For those traveling indirectly (i.e. requiring multiple flights), major transit points where flight connections are made represent another potential frontier for intervention. In this Exhibit, the top five international and/or domestic cities used by passengers as transit points en route to Halifax are shown.

Saskatchewan and Manitoba

Exhibit 70 illustrates an important metric of global connectivity. All cities with international airports worldwide are shown in "degrees of separation" from the provinces of Saskatchewan and Manitoba. In this analysis, "degrees of separation" are measured by the minimum number of flight connections required to land in any city in Saskatchewan or Manitoba. In network theory, directly connected nodes within a network tend to have the highest flows between them. With increasing degrees of separation (i.e. increasing number of steps) between nodes, network flows tend to decrease. In the case of Saskatchewan and Manitoba, the provinces are most vulnerable to infectious disease threats originating in cities shown in red (i.e. from which they have non-stop flights arriving), followed by cities in tan (i.e. from which at least one flight connection is required to enter Saskatchewan or Manitoba), and finally cities in green and blue (i.e. from which at least two and three flight connections respectively are required to enter Saskatchewan or Manitoba).

Exhibit 71 complements the findings of the previous Exhibit by illustrating areas of the world where passengers most frequently originate when traveling to the provinces of Saskatchewan and Manitoba. It is important to note that hot-spots shown in this map reflect the true origins of international passengers in that all flight connections (if applicable) for each passenger trip have been accounted for. Since this type of map was designed as a visual aid, it should not be used to delineate the precise geographic boundaries of hot-spots. When interpreting this type of heat-map, readers should first examine the Volume of Passenger Arrivals bar to determine the maximum number of passengers represented by the map's hot-spots. Furthermore, different heat-maps should not be compared with one another, but rather interpreted independently. Complementing this heat map is Exhibit 72, which shows the number of international passengers entering Saskatchewan and Manitoba from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Northern Canada: Yukon Territory, Northwest Territories, and Nunavut

Exhibit 73 illustrates an important metric of global connectivity. All cities with international airports worldwide are shown in "degrees of separation" from Northern Canada. In this analysis, "degrees of separa-

Exhibit 70: Web Map

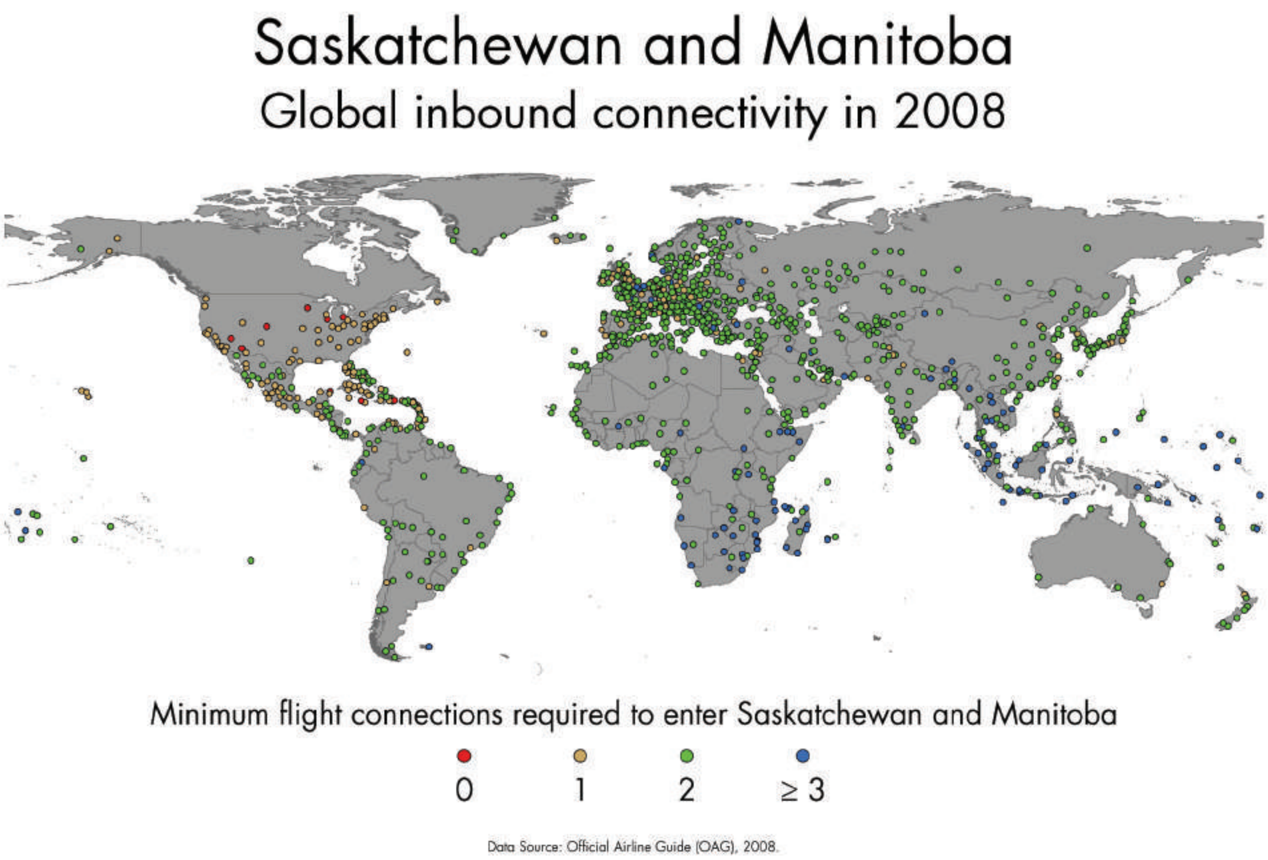


Exhibit 71: Web Map

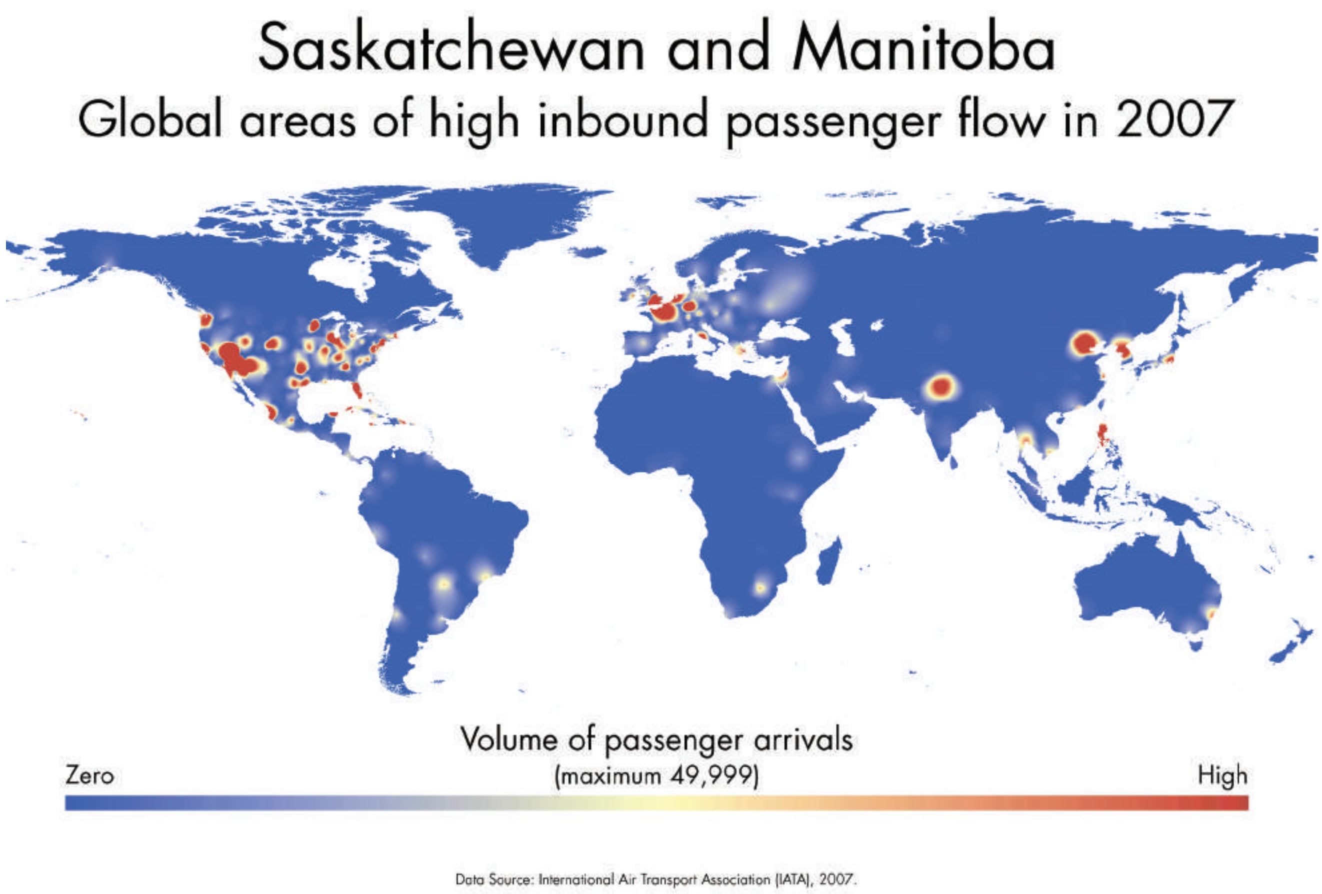


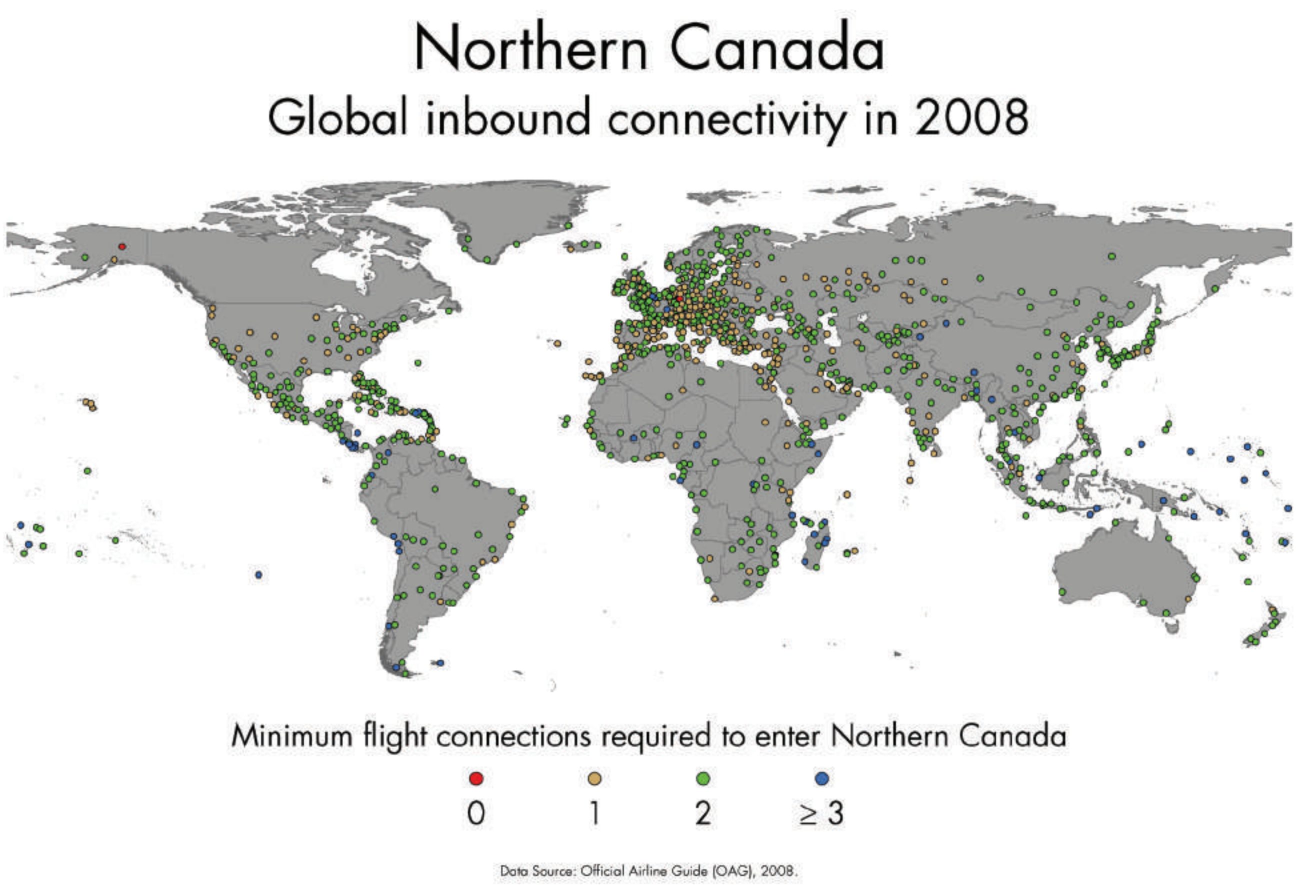
Exhibit 72:

Saskatchewan and Manitoba - Volume of International Passenger Arrivals from Leading Global Points of Origin*				
City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Manila	Philippines	10518	9.4%	9.4%
Cancun	Mexico	9877	8.9%	18.3%
Puerto Vallarta	Mexico	6477	5.8%	24.1%
Beijing	China	5196	4.7%	28.8%
Hong Kong	Hong Kong (sar) China	3896	3.5%	32.3%
Seoul	Korea, Republic of	3631	3.3%	35.5%
Delhi	India	3443	3.1%	38.6%
Montego Bay	Jamaica	2857	2.6%	41.2%
Punta Cana	Dominican Republic	2673	2.4%	43.6%
Tokyo	Japan	2650	2.4%	45.9%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Exhibit 73: Web Map



tion" are measured by the minimum number of flight connections required to land in any city in Northern Canada. In network theory, directly connected nodes within a network tend to have the highest flows between them. With increasing degrees of separation (i.e. increasing number of steps) between nodes, network flows tend to decrease. In the case of Northern Canada, the region is most vulnerable to infectious disease threats originating in cities shown in red (i.e. from which it has non-stop flights arriving), followed by cities in tan (i.e. from which at least one flight connection is required to enter Northern Canada), and finally cities in green and blue (i.e. from which at least two and three flight connections respectively are required to enter Northern Canada).

Exhibit 74 complements the findings of the previous Exhibit by illustrating areas of the world where passengers most frequently originate when traveling to Northern Canada. It is important to note that hot-spots shown in this map reflect the true origins of international passengers in that all flight connections (if applicable) for each passenger trip have been accounted for. Since this type of map was designed as a visual aid, it should not be used to delineate the precise geographic boundaries of hot-spots. When interpreting this type of heat-map, readers should first examine the Volume of Passenger Arrivals bar to determine the maximum number of passengers represented by the map's hot-spots. Furthermore, different heat-maps should not be compared with one another, but rather interpreted independently. Complementing this heat map is Exhibit 75, which shows the number of international passengers entering Northern Canada from the top ten points of origin worldwide, excluding cities in i) the United States, and ii) Western, Northern and Southern Europe, and iii) Australia, New Zealand, and Pacific Islands.

Exhibit 74: Web Map

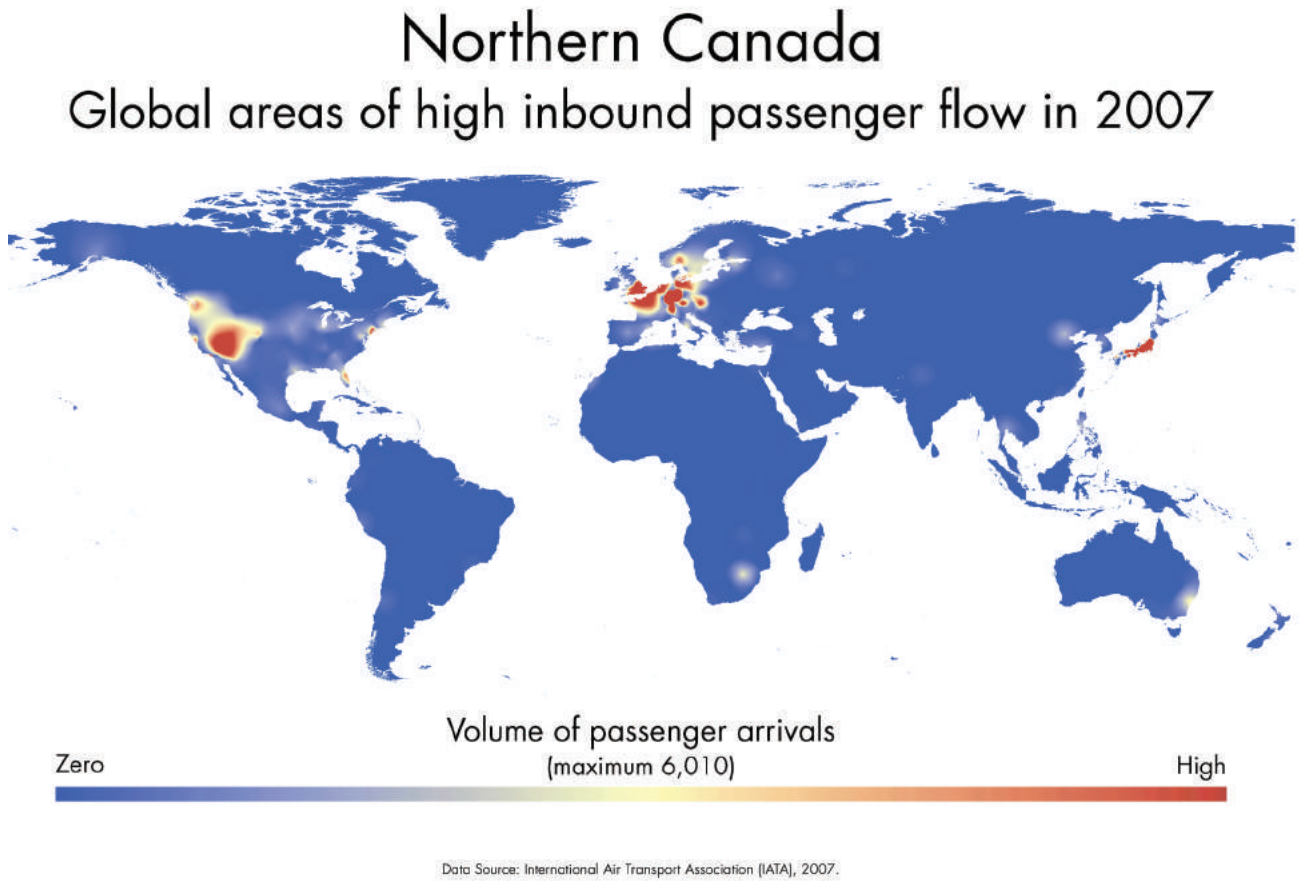


Exhibit 75:

Northern Canada - Volume of International Passenger Arrivals from Leading Global Points of Origin*

City	Country	Annual Volume of Passengers	% Annual Volume*	Cumulative % Annual Volume*
Tokyo	Japan	2735	54.4%	54.4%
Osaka	Japan	1063	21.1%	75.6%
Nagoya	Japan	300	6.0%	81.5%
Fukuoka	Japan	133	2.6%	84.2%
Prague	Czech Republic	97	1.9%	86.1%
Johannesburg	South Africa	69	1.4%	87.5%
Larnaca	Cyprus	51	1.0%	88.5%
Beijing	China	48	1.0%	89.4%
Manila	Philippines	48	1.0%	90.4%
Sapporo	Japan	46	0.9%	91.3%

*Excluding Cities in the United States; Western, Southern and Northern Europe; Australia, New Zealand and the Pacific Islands

Data Source: International Air Transport Association (IATA), 2007

Disease Emergence & Control Indicators

Areas of the world generating high volumes of international air traffic into Canada do not necessarily pose the greatest risk of exporting infectious diseases. The risk of an infectious disease threat spreading into Canada from another part of the world is a composite of the following conditional probabilities:

i) that an infectious disease threat will emerge at the source location
ii) that the source location will be capable of containing the threat,
iii) that people traveling out of the source location will arrive in Canada.

While conditions i) and ii) cannot be precisely measured, a series of ten indicator variables have been selected as surrogate markers.

1. Human population density – This indicator is presented as a gridded map quantifying the size of human populations for each square kilometre grid worldwide. This variable was selected since the focus of this report is on communicable infectious diseases of humans. Data are presented in Exhibit 76 as a gridded map of the world.

2. Poultry population density – This indicator is also presented as gridded map quantifying the size of poultry populations for each square kilometre grid worldwide. This variable was selected since this report focuses attention on highly pathogenic avian influenza and its risk of triggering the next influenza pandemic. Data are presented in Exhibit 77 as a gridded map of the world.

3. Human and poultry population co-density – This indicator variable is a composite of the above two variables, taking into consideration areas of the world where humans and poultry coexist to their greatest extent. This variable was also selected since it reflects the potential for avian influenza to trigger the next influenza pandemic. Data are presented in Exhibit 78 as a gridded map of the world.

4. Highly pathogenic avian influenza in humans – This country-level indicator is based on reported data of H5N1 avian influenza cases in humans worldwide between January 1st, 2003 and December 31st, 2008. This map illustrates that a significant number of human cases have been reported in Indonesia, Vietnam, China, and Egypt among other countries. Data are presented in Exhibit 79 as a choropleth map of the world.

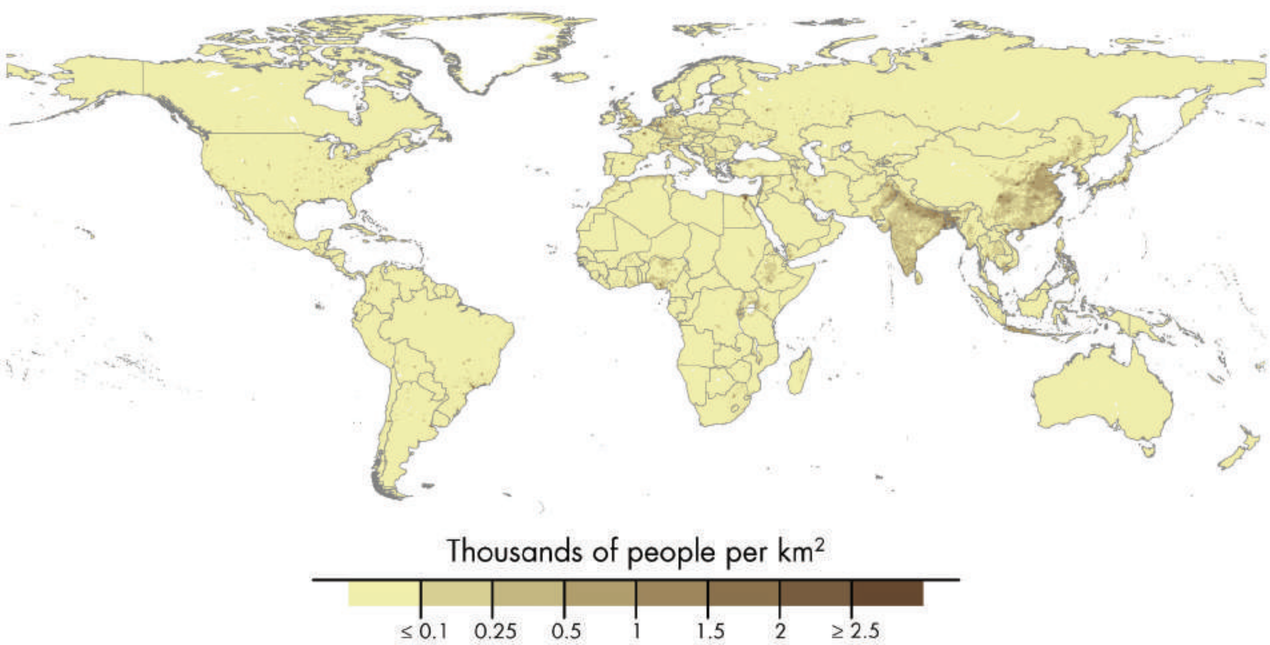
5. Cities with operational laboratories reported to hold WHO risk group 4 microorganisms – This world map displays the locations of known laboratories reported to hold highly dangerous infectious pathogens. Although these laboratories tend to be very secure, there are precedents of accidental breaches, which could trigger international outbreaks. Data are illustrated in Exhibit 80 in a world map.

6. National economic status – This country-level indicator provides information about Gross National Income (GNI) per capita. Poverty may contribute to environmental conditions (e.g. crowding, inadequate sanitation etc.) that foster the emergence of dangerous infectious diseases. Data are presented in Exhibit 81 as a choropleth map of the world.

7. National health expenditures – This

Exhibit 76: Web Map

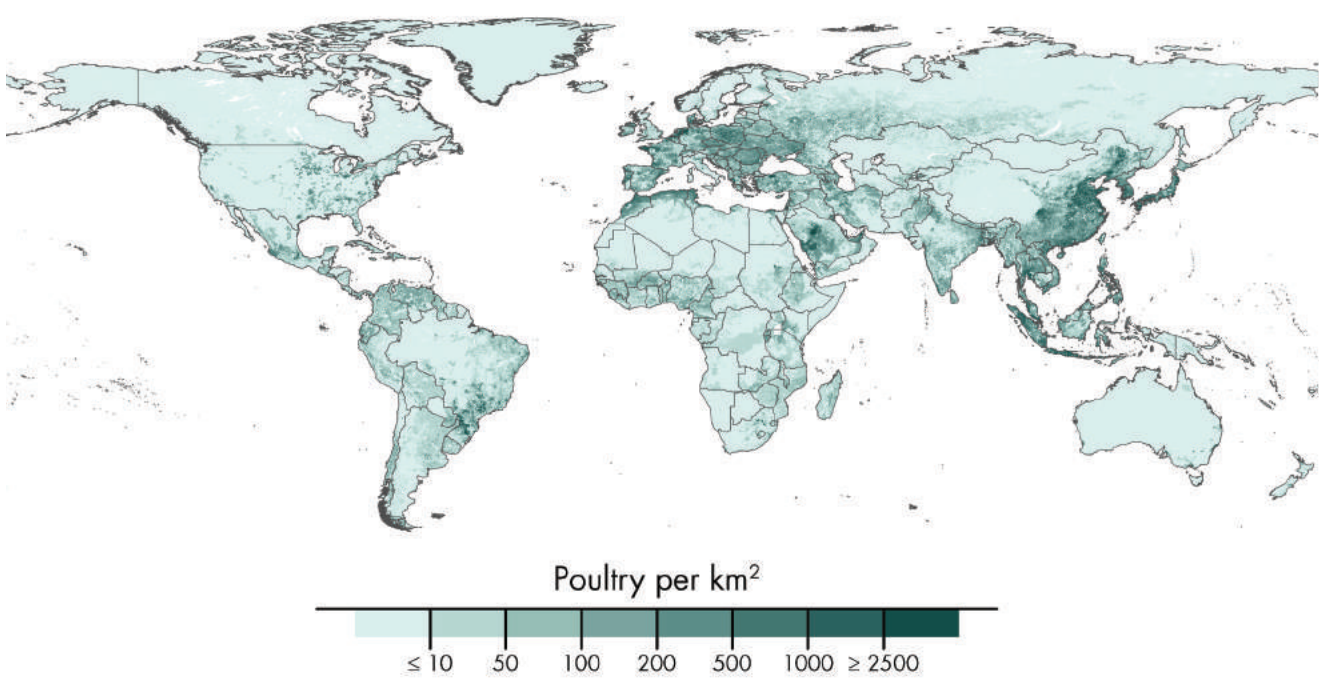
Global Human Population Density



Data Source: Socioeconomic Data and Applications Centre (SEDAC), 2005.

Exhibit 77: Web Map

Global Poultry Population Density



Data Source: Food and Agriculture Organization of the United Nations (FAO), 2007.

Exhibit 78: Web Map

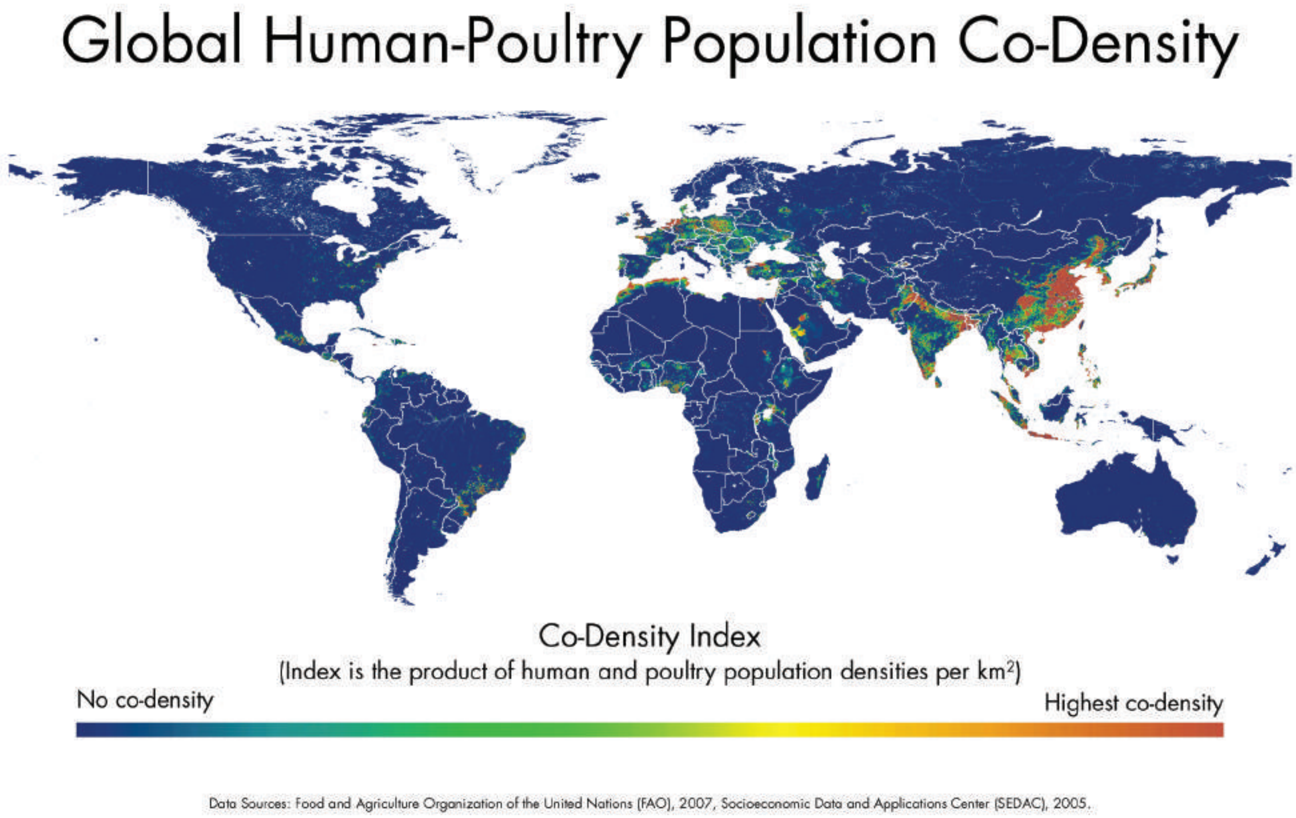


Exhibit 79: Web Map

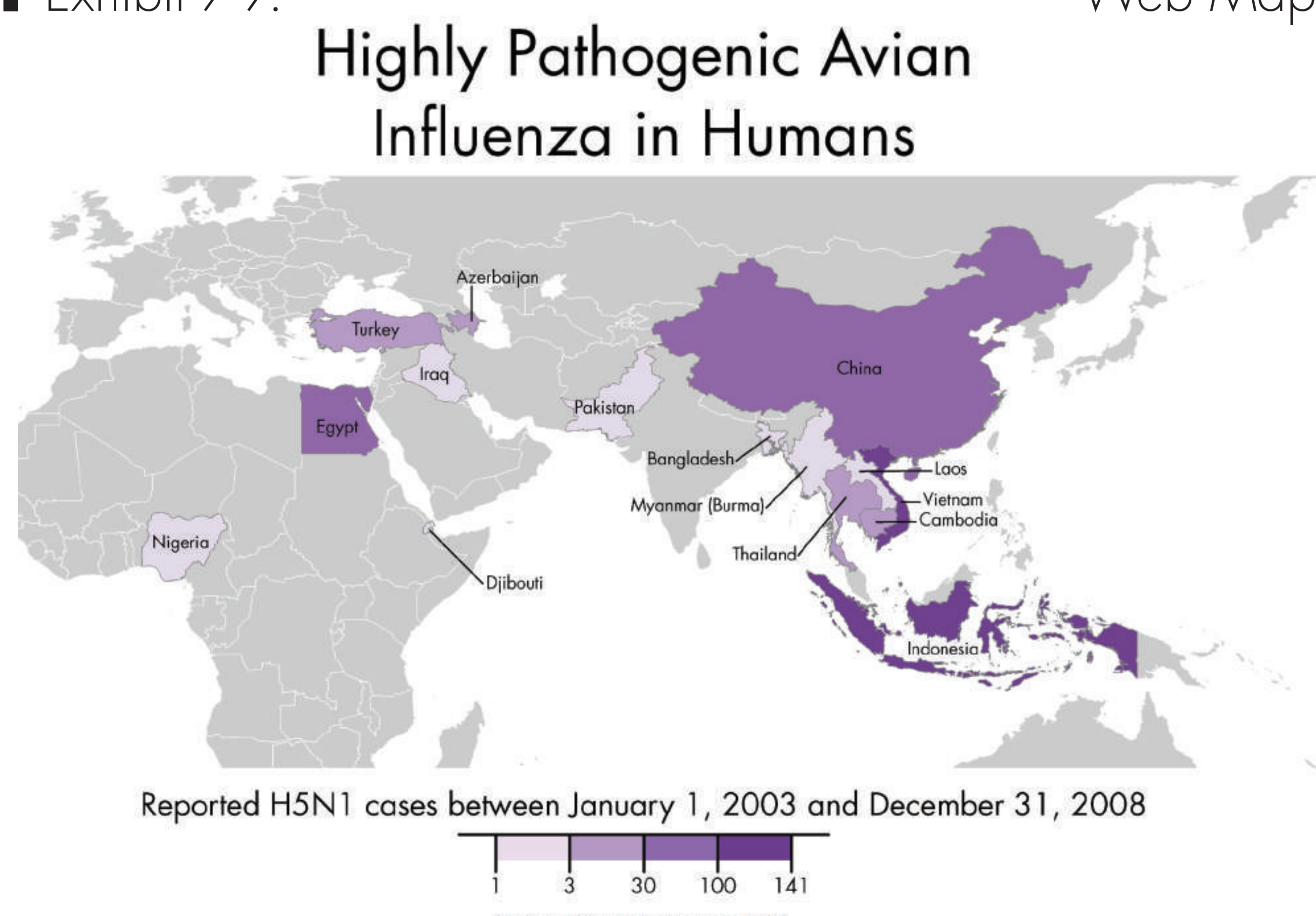
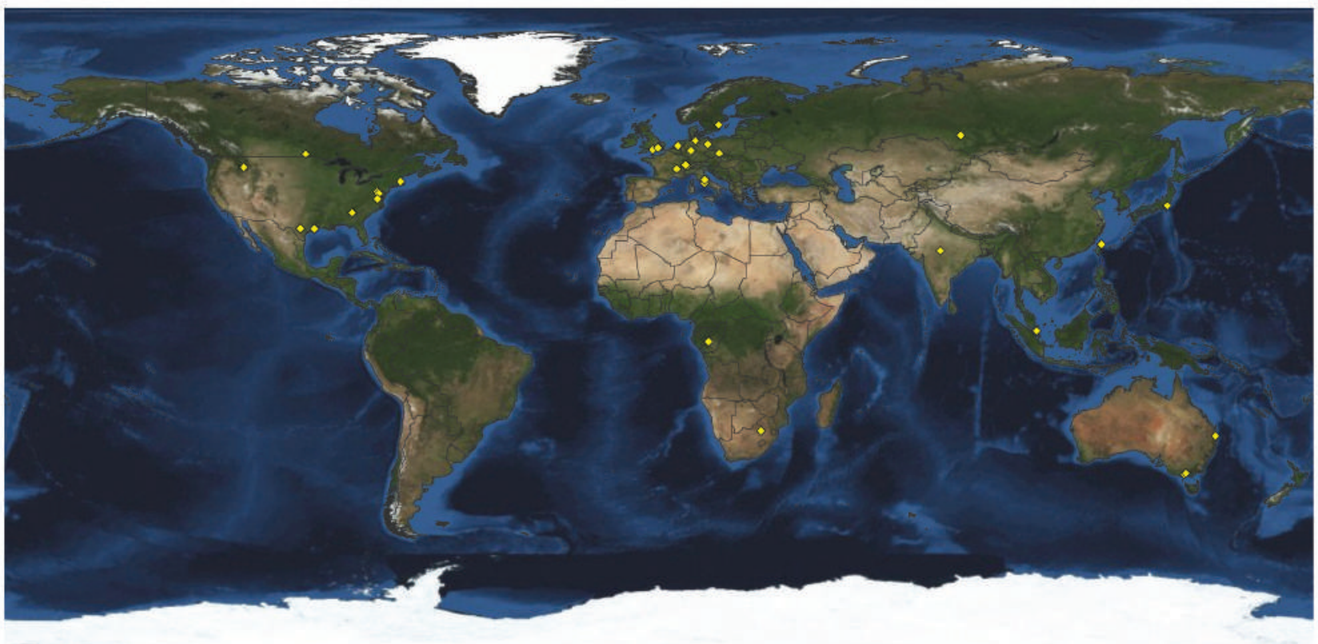


Exhibit 80: Web Map

Cities with Operational Laboratories Reported to Hold WHO Risk Group 4 Microorganisms

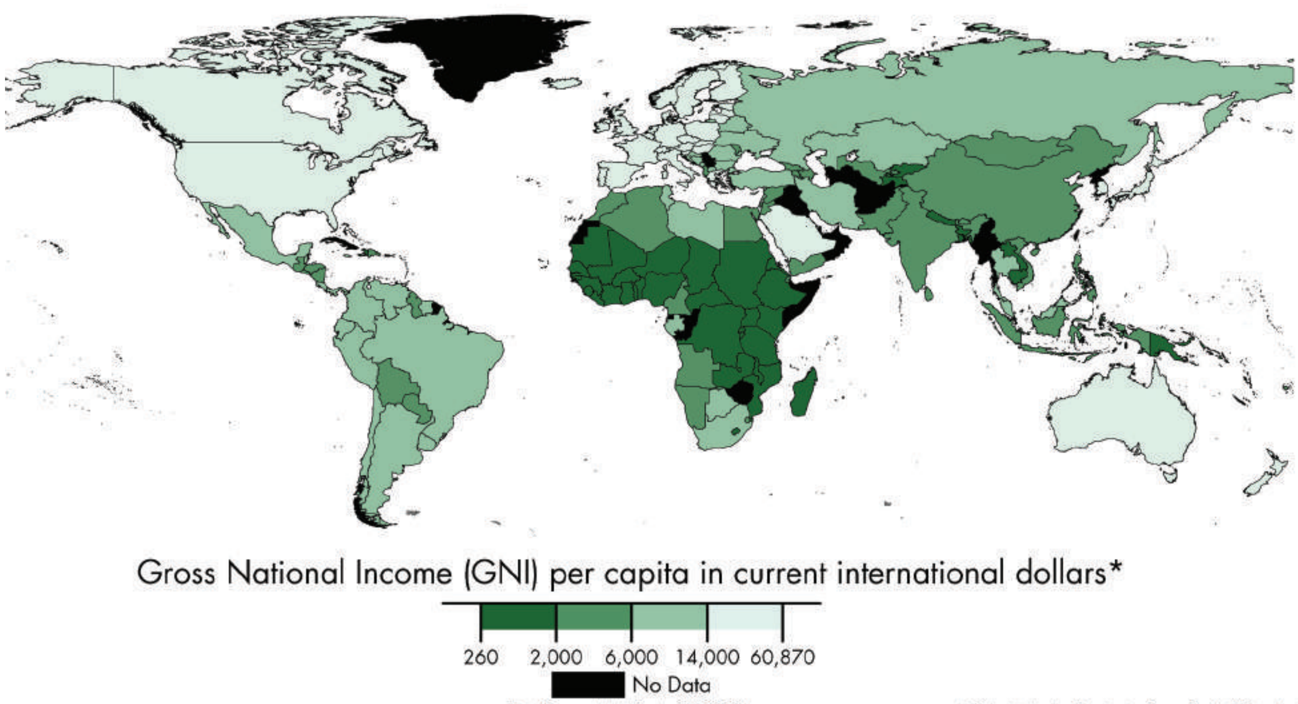


Labs currently under construction: The United States (6 labs), Germany (1 lab), Switzerland (1 lab), Netherlands (1 lab).

Locations of known laboratories in operation.

Exhibit 81: Web Map

National Economic Status



country-level indicator provides information about health resources used per capita. Presumably countries with fewer resources will experience greater difficulty detecting, confirming, and characterizing the presence of an infectious disease threat. Furthermore, this indicator presumably speaks to the resources available to contain an infectious disease threat once it has been identified. Data are presented in Exhibit 82 as a choropleth map of the world.

8. National physician density – This country-level indicator provides information about human resources available for healthcare. Specifically, this indicator quantifies the number of physicians available per 1000 people in the general population. Since data have been reported at different times by different countries, three colour ramps are shown. Countries in green are based on older data estimates (reported between 1990 and 2000), followed by those in red (reported between 2001 and 2004), and finally those in blue (reported between 2005 and 2008). Presumably, countries with fewer physicians per capita will experience greater difficulty detecting and managing serious infectious disease threats. Data are presented in Exhibit 83 as a choropleth map of the world.

9. National nurse density – This country-level indicator provides information about human resources available for healthcare. Specifically, this indicator quantifies the number of nurses available per 1000 people in the general population. Presumably, countries with fewer nurses per capita will have greater difficulty detecting and managing serious infectious disease threats. Data are presented in Exhibit 84 as a choropleth map of the world.

10. National hospital bed density – This country-level indicator provides information about national healthcare resources available for conditions requiring hospitalization. Specifically, this indicator quantifies the number of hospital beds available per 1000 people in the general population. Since data have been reported at different times by different countries, two colour ramps are shown. Countries in green are based on older data estimates (reported between 2000 and 2004) while those in blue are based on more recent data (reported between 2005 and 2007). Presumably, countries with fewer hospital beds per capita will have greater difficulty managing serious infectious disease threats requiring hospitalization. Data are presented in Exhibit 85 as a choropleth map of the world.

Exhibit 82: Web Map

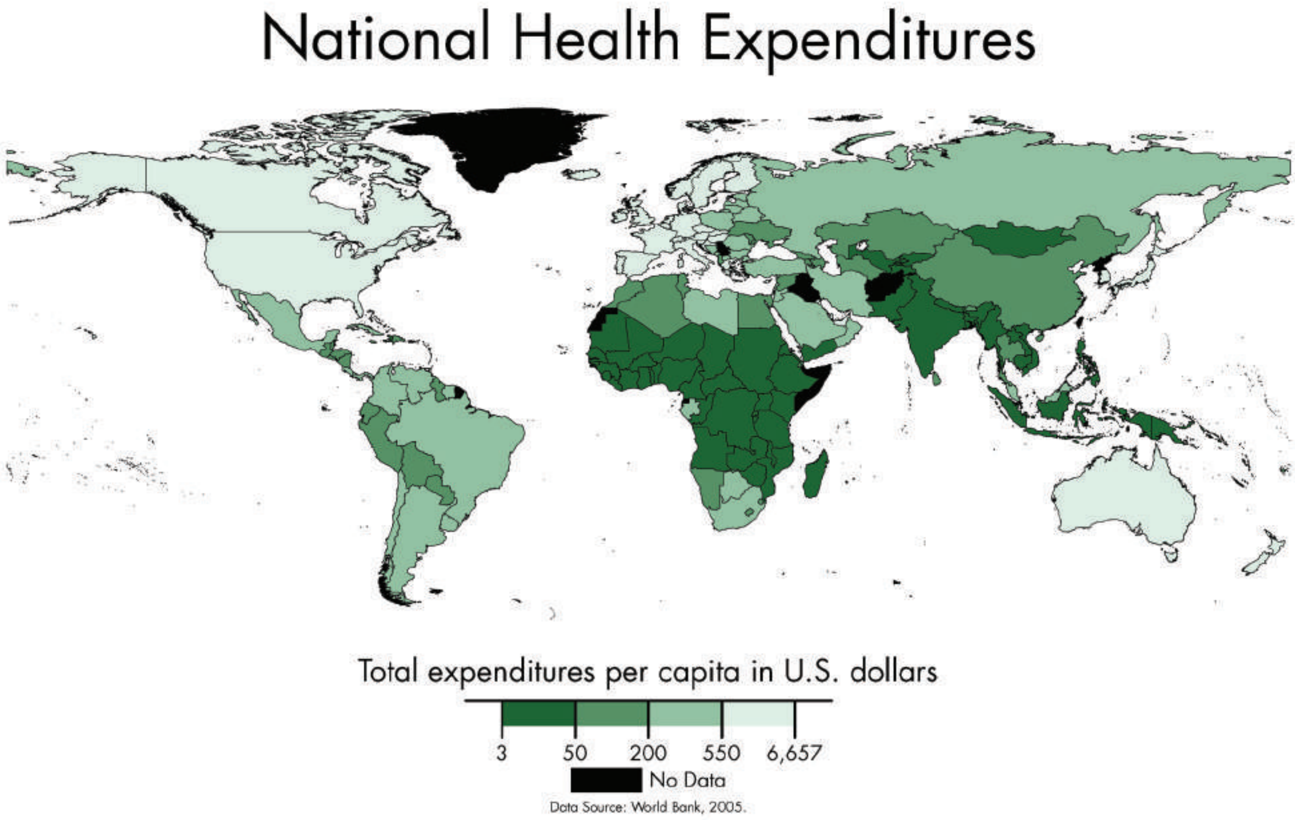


Exhibit 83: Web Map

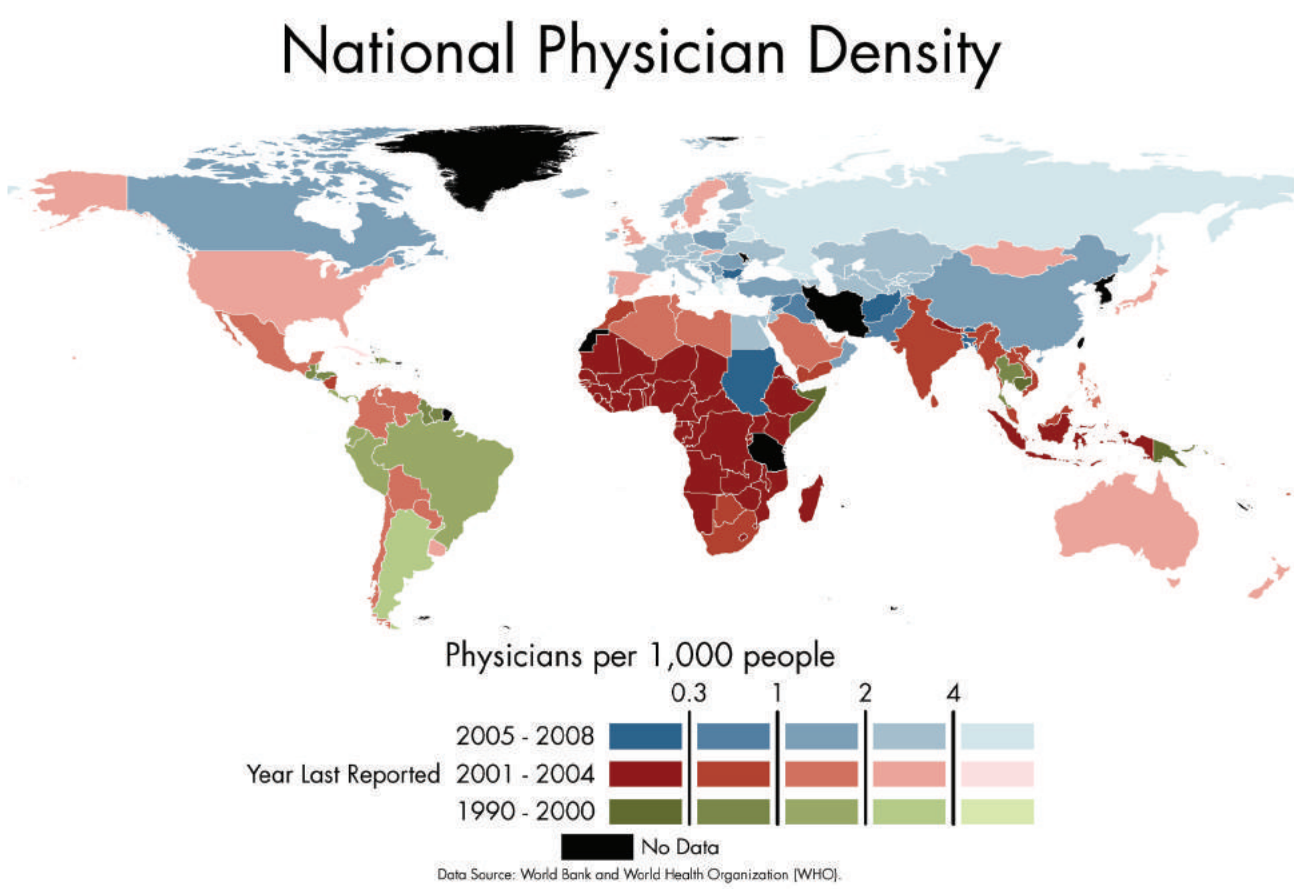


Exhibit 84: Web Map

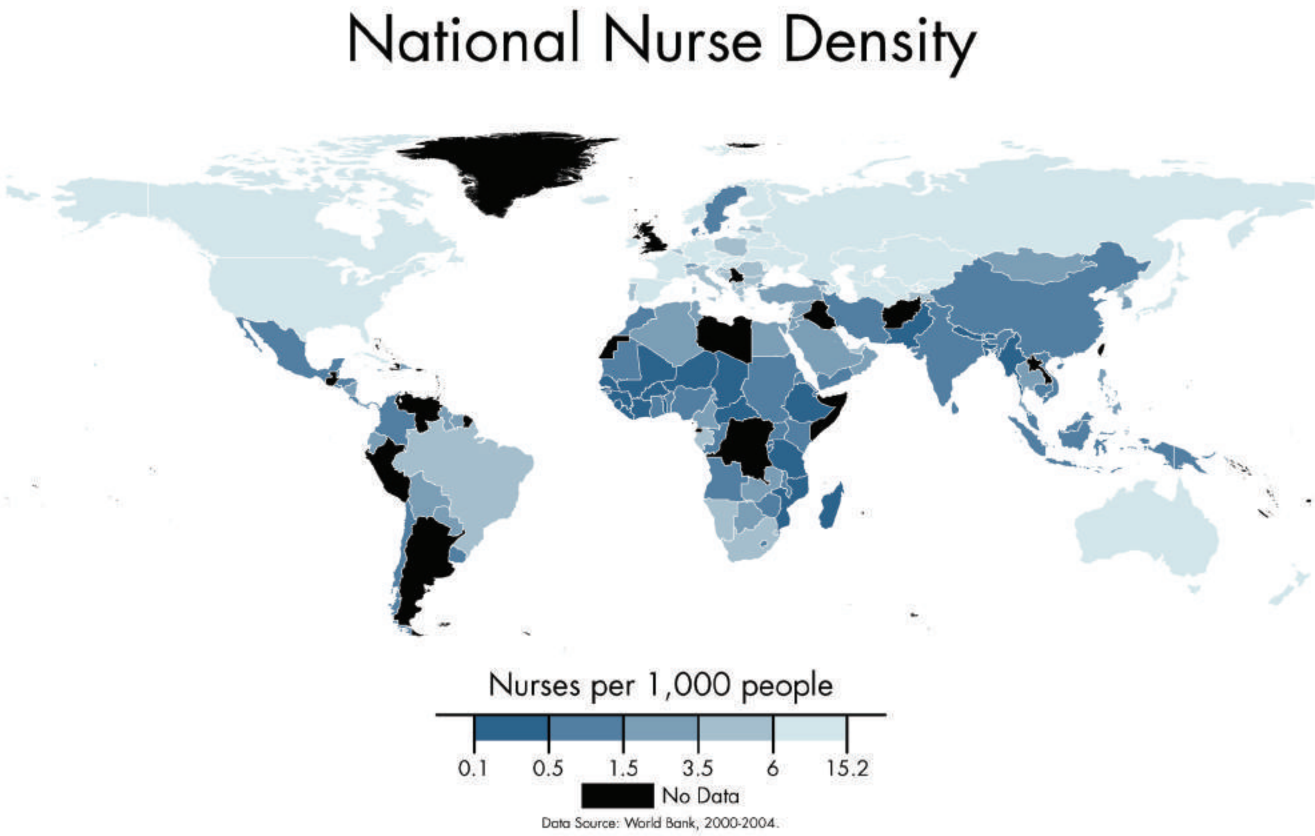
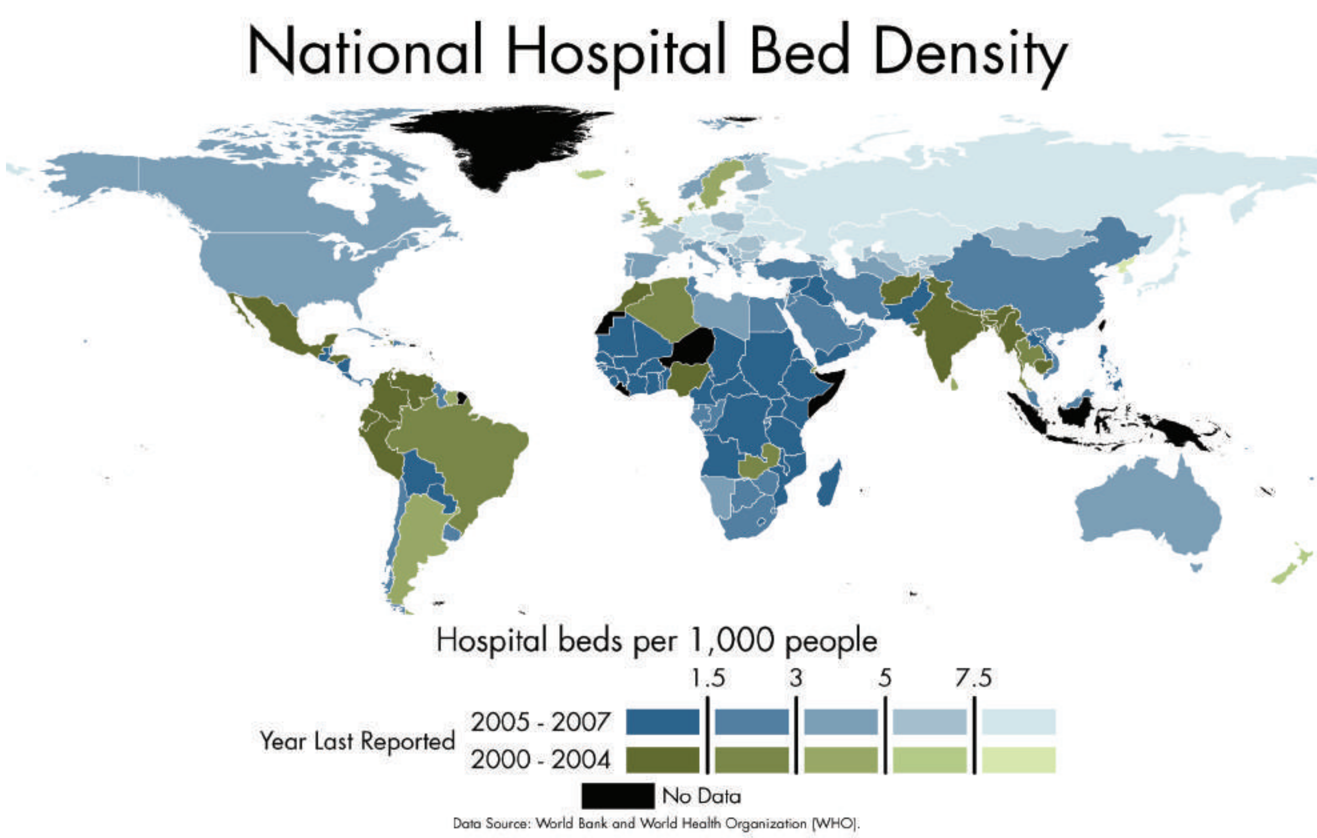


Exhibit 85: Web Map



Global Simulations

The results of seven global simulation scenarios are shown below. These simulations are of the outbound variety, indicating that they are initiated with the "planting" of an infectious "seed" at a selected city. Subsequently, the spatial patterns of dissemination via the global airline transportation network are observed over a 21-day period. Each scenario is simulated 5000 times. For each simulation, it is assumed that there are no effective measures in place to prevent infected travelers from boarding commercial aircraft. Model parameters are based upon the viral characteristics of the (seasonal) influenza virus. Additional details about outbound simulations are found in the Mathematical Modeling section of the Scientific Methods.

Four of the cities selected as hypothetical epicentres for outbound simulations were chosen based on the global epidemiology of highly pathogenic avian influenza. For example, Jakarta, Hanoi, Hong Kong, and Cairo were selected given that the greatest numbers of H5N1 avian influenza cases in humans have been reported in Indonesia, Vietnam, China, and Egypt. The cities of Johannesburg, Mumbai and Sao Paulo were selected to consider disease emergence from other geographic regions of the world including Sub-Saharan Africa, South Asia, and South America. For each map, graduated symbols are shown to represent the proportion of simulations resulting in disease importation.

Exhibit 86 illustrates the global dissemination pathways of influenza from Jakarta, Indonesia. Given Canada's relative lack of connectivity with Indonesia, the overall probability of importation into Canadian cities during the simulation's 21-day period is low, but comparable between Toronto and Vancouver. No other Canadian cities had simulated importations.

Exhibit 87 illustrates the global dissemination pathways of influenza from Hanoi, Vietnam. The probability of importation into Canadian cities is unevenly distributed, with Toronto experiencing a nearly two-fold greater risk than Vancouver, a seven-fold greater risk than Montreal, and a fifteen-fold greater risk than Calgary. In this analysis, Toronto and Vancouver have the highest simulated risk of importation among any city in the Americas.

Exhibit 88 illustrates the global dissemination pathways of influenza from Hong Kong, China. Among the seven simulations scenarios performed, the probability of importation into Canadian cities is greatest when influenza originates in Hong Kong. Moreover, the probability of importation into Canada is unevenly distributed, with Vancouver experiencing a two-fold greater risk than Toronto, a six-fold greater risk than Calgary, and an eighteen-fold greater risk than Ottawa. Disease importations were observed but were very infrequent in other cities such as Victoria, B.C., Montreal, and Edmonton. Incidentally, the simulated worldwide distribution of influenza shown here bears a striking resemblance to the actual worldwide distribution of SARS, which disseminated out of Hong Kong in 2003. Furthermore, the increased probability of importation into Vancouver relative to Toronto is consistent with empirical observations during SARS, as Vancouver received a greater number of imported cases than Toronto.

Exhibit 86: Web Map

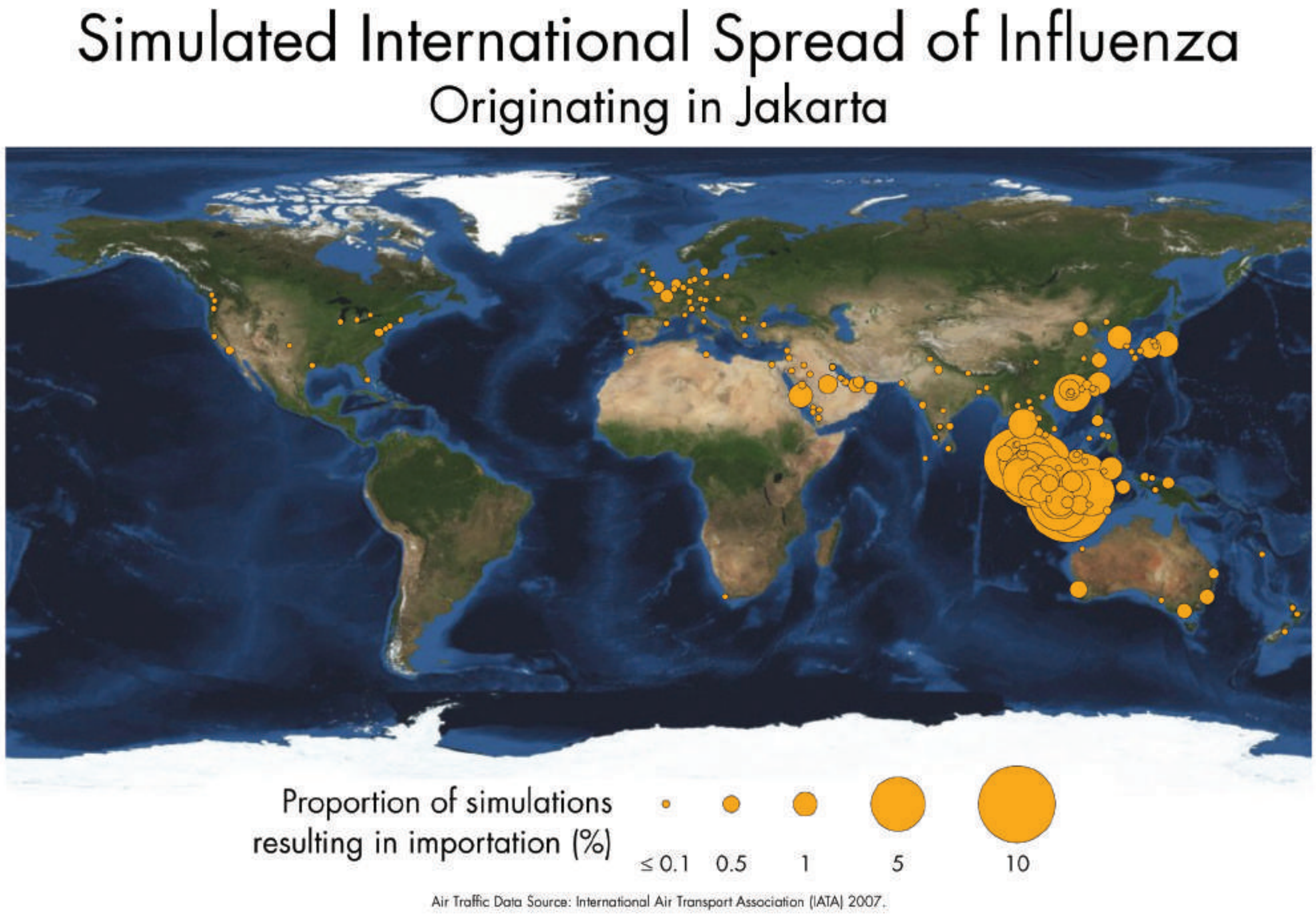


Exhibit 87: Web Map

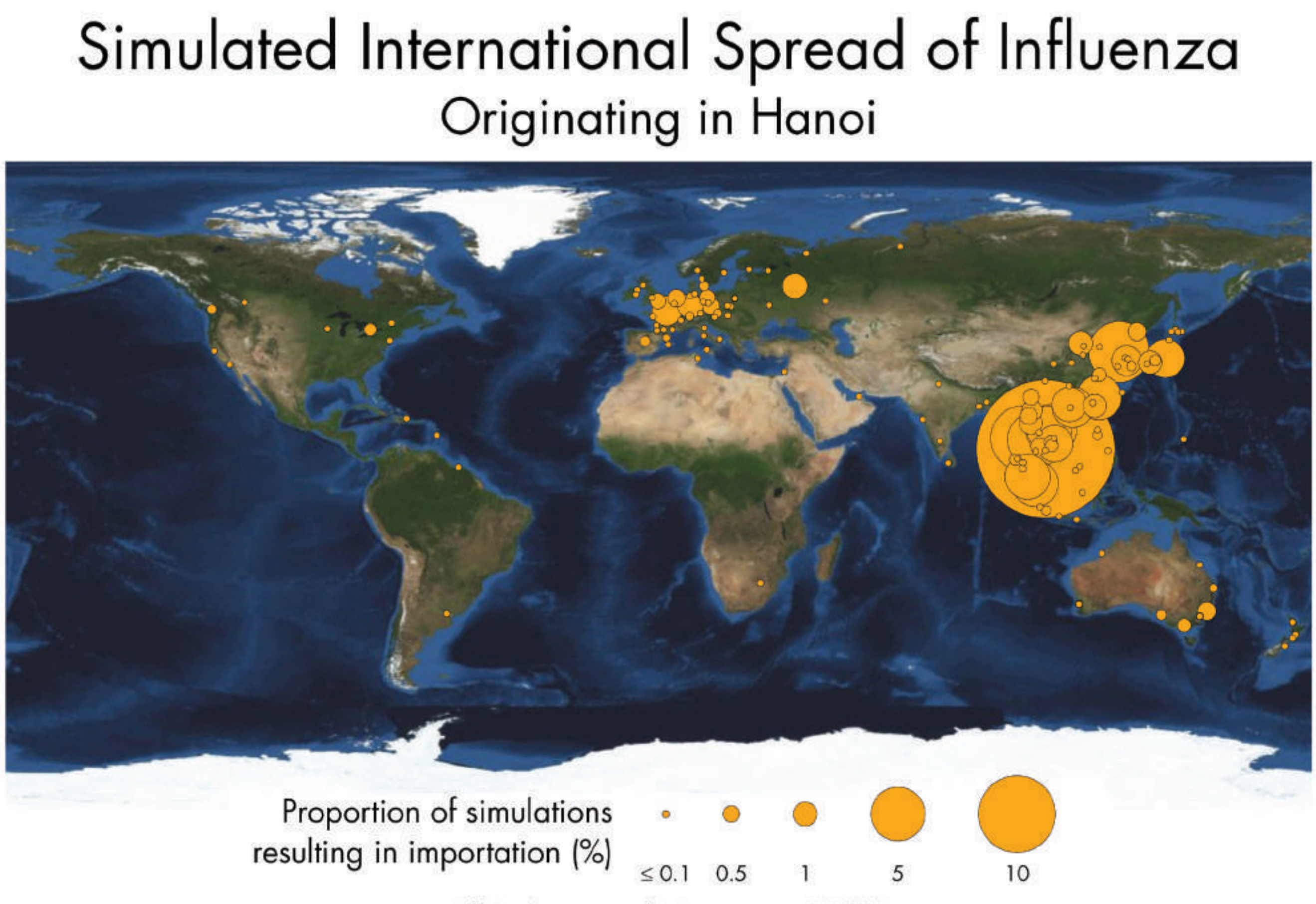
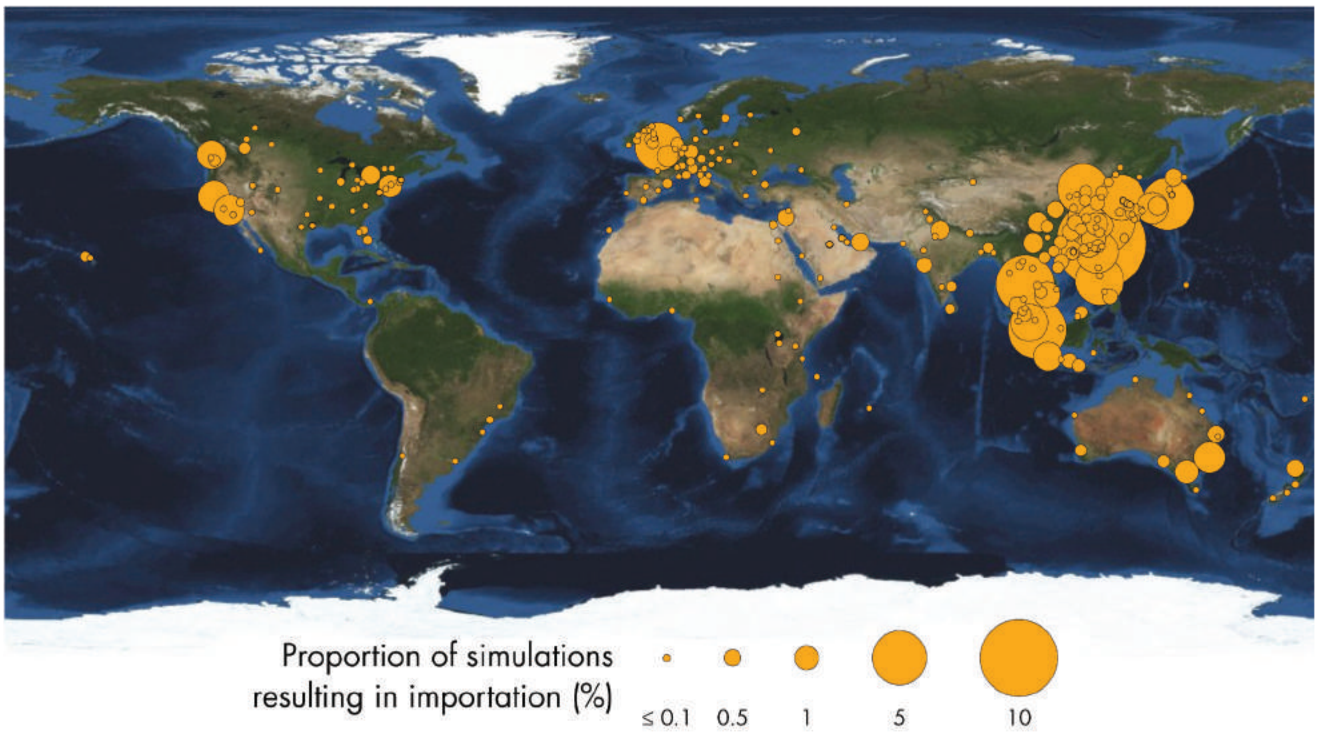


Exhibit 88: Web Map

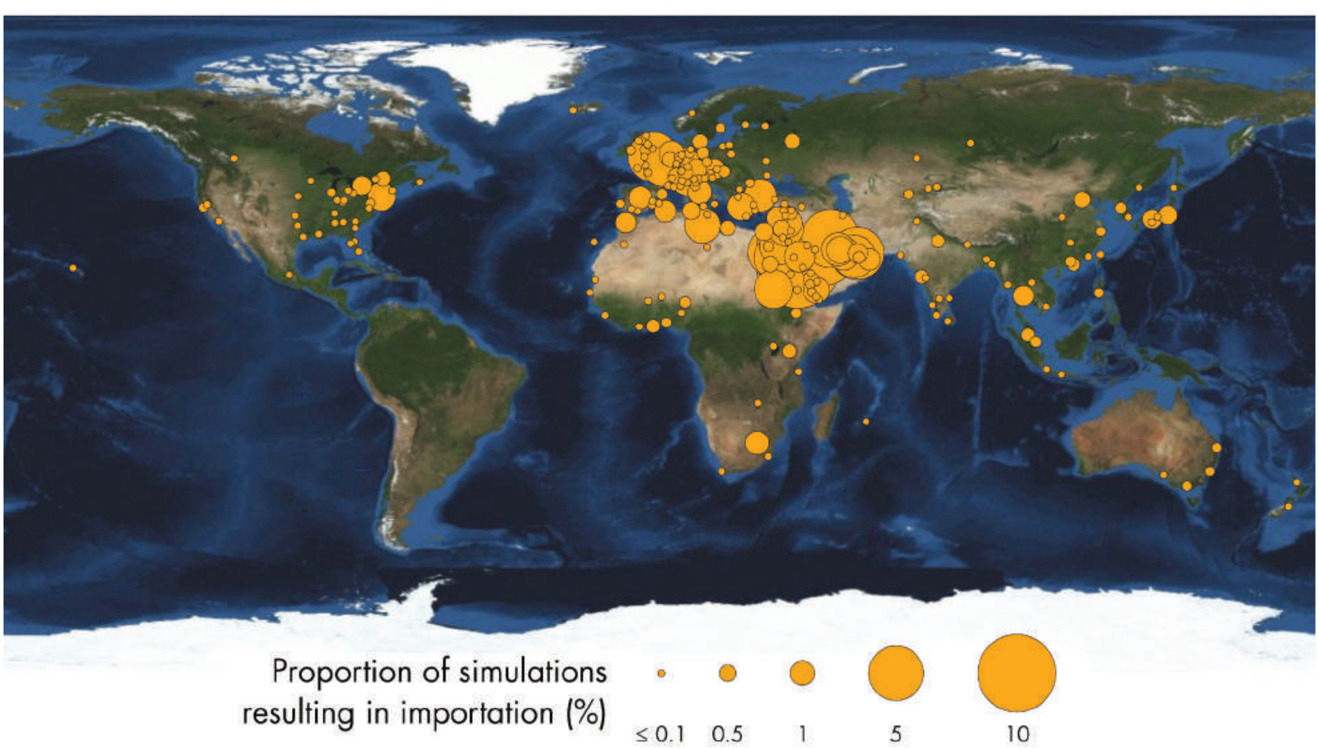
Simulated International Spread of Influenza
Originating in Hong Kong



Air Traffic Data Source: International Air Transport Association (IATA) 2007.

Exhibit 89: Web Map

Simulated International Spread of Influenza
Originating in Cairo



Air Traffic Data Source: International Air Transport Association (IATA) 2007.

Exhibit 89 illustrates the global dissemination pathways of influenza from Cairo, Egypt. The probability of importation into Canadian cities is largely distributed between Toronto and Montreal, with Toronto experiencing a 1.5-fold greater risk. In this analysis, New York City, Toronto and Montreal have the highest simulated risk of importation of any city in the Americas.

Exhibit 90 illustrates the global dissemination pathways of influenza from Johannesburg, South Africa. The overall probability of importation into Canada during the 21-day simulation period is low, with Toronto having the highest risk among Canadian cities. Overall, Toronto carries twice the risk of importation of Montreal, and three times the risk of Vancouver and Edmonton. Compared to U.S. cities, Toronto has one-fifth the risk of importation of New York City, nearly one-half the risk of Washington, D.C., and comparable risks to Atlanta and San Francisco.

Exhibit 91 illustrates the global dissemination pathways of influenza from Mumbai, India. The probability of importation into the Americas is highest for New York City, followed by Toronto, which has one-third of New York's risk. Chicago and Los Angeles each have approximately one-fifth the risk of New York City. Outside of Toronto, importation events were infrequently observed in Canada (Montreal and Vancouver had one-third and one-sixth the importation risk of Toronto respectively).

Exhibit 92 illustrates the global dissemination pathways of influenza from Sao Paulo, Brazil. Given the geographic origin of disease, there is extensive simulated dissemination throughout the Americas. In the United States, the risk of importation is greatest for cities like New York City, Miami, and Orlando, while in Canada the highest risk falls to Toronto.

The results of an additional four simulated scenarios are shown below. These simulations are of the inbound variety, indicating that they are initiated with the "planting" of an influenza "seed" in 596 of the world's major cities. The spatial dissemination patterns from each city are then observed over a 21-day period. Each scenario is simulated 2000 times. This process is then repeated for each quarter of the year to account for possible seasonal variation. For each simulation, it is assumed that there are no effective measures in place to prevent infected travelers from boarding commercial aircraft. Model parameters are based upon the viral characteristics of the (seasonal) influenza virus. The probability of importation from each "seed city" is then calculated for each quarter to identify which cities in the world possess the greatest potential to export infectious diseases into Canada.

Exhibit 93 displays the simulated spread of influenza into Canada from major cities around the world during the first quarter.

Exhibit 94 displays the simulated spread of influenza into Canada from major cities around the world during the second quarter.

Exhibit 95 displays the simulated spread of influenza into Canada from major cities around the world during the third quarter.

Exhibit 96 displays the simulated spread of influenza into Canada from major cities around the world during the fourth quarter.

Exhibit 90: Web Map

Simulated International Spread of Influenza
Originating in Johannesburg

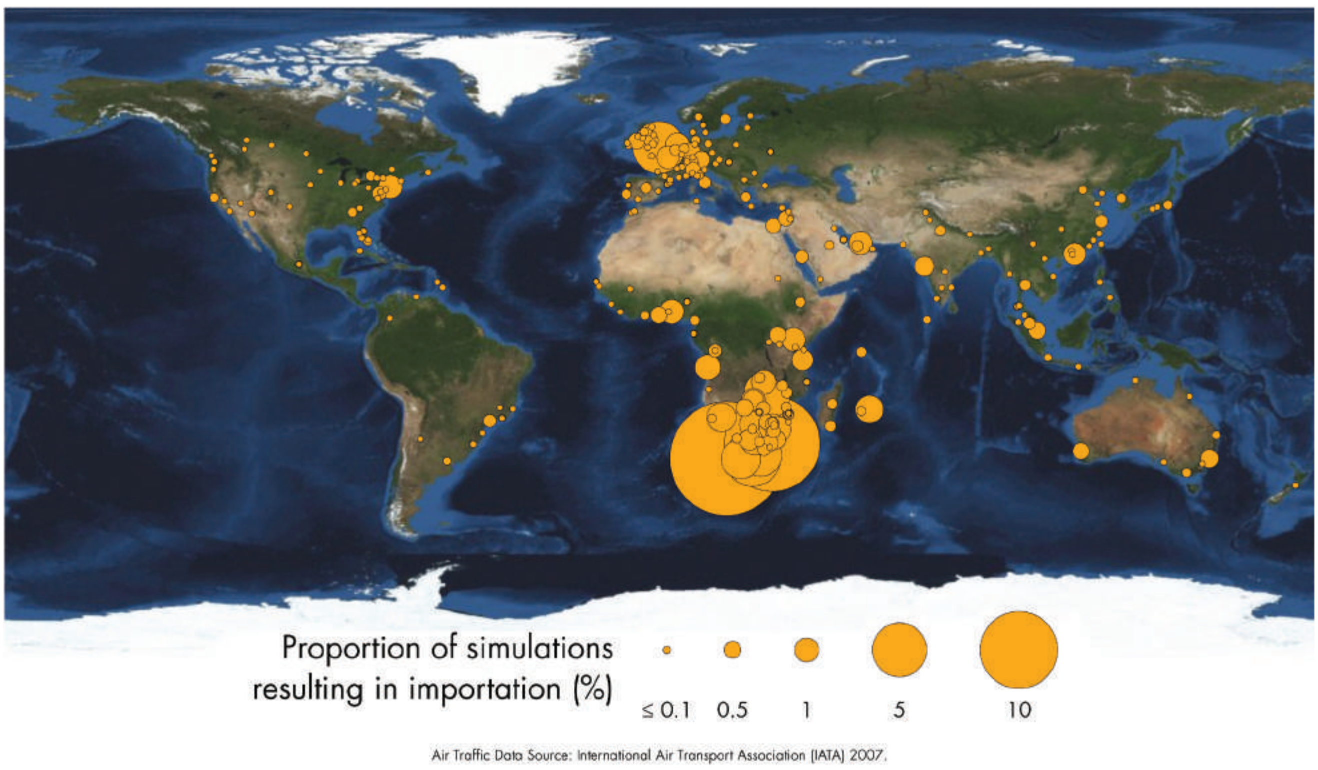


Exhibit 91: Web Map

Simulated International Spread of Influenza
Originating in Mumbai

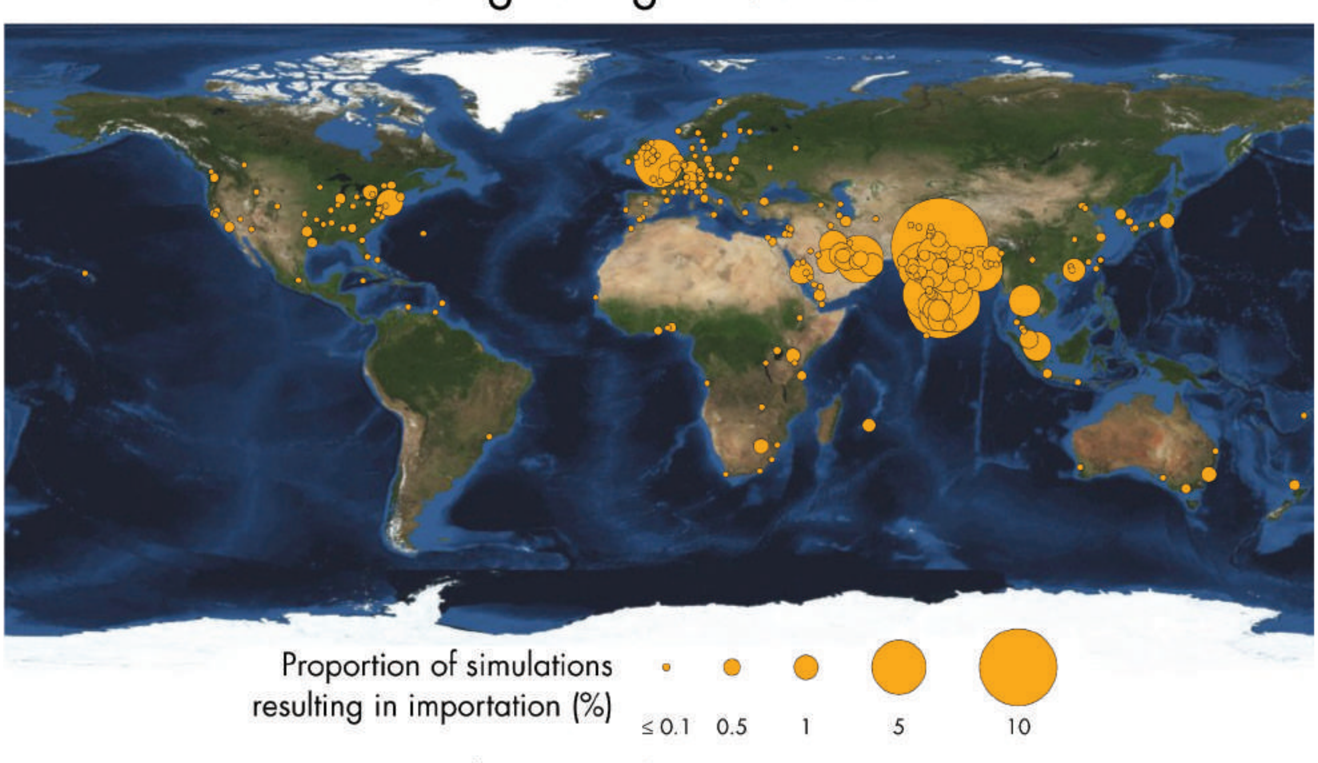
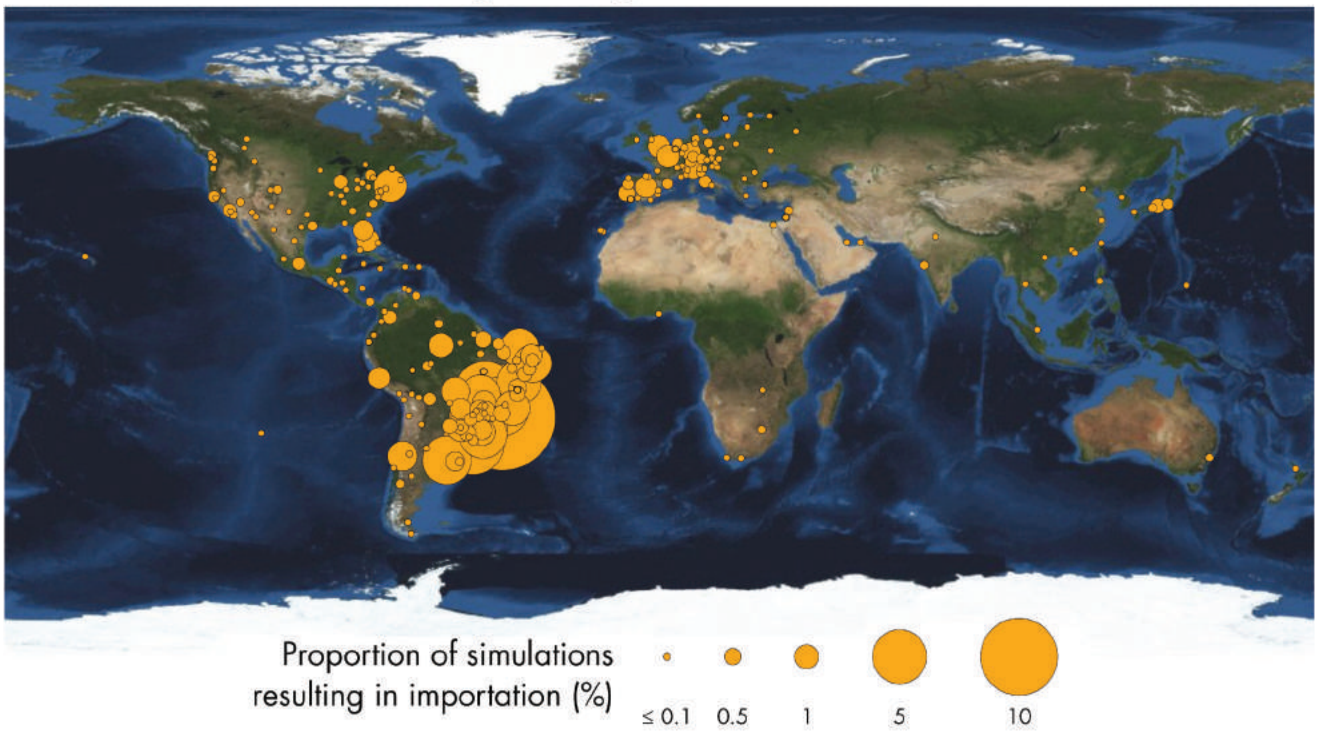


Exhibit 92: Web Map

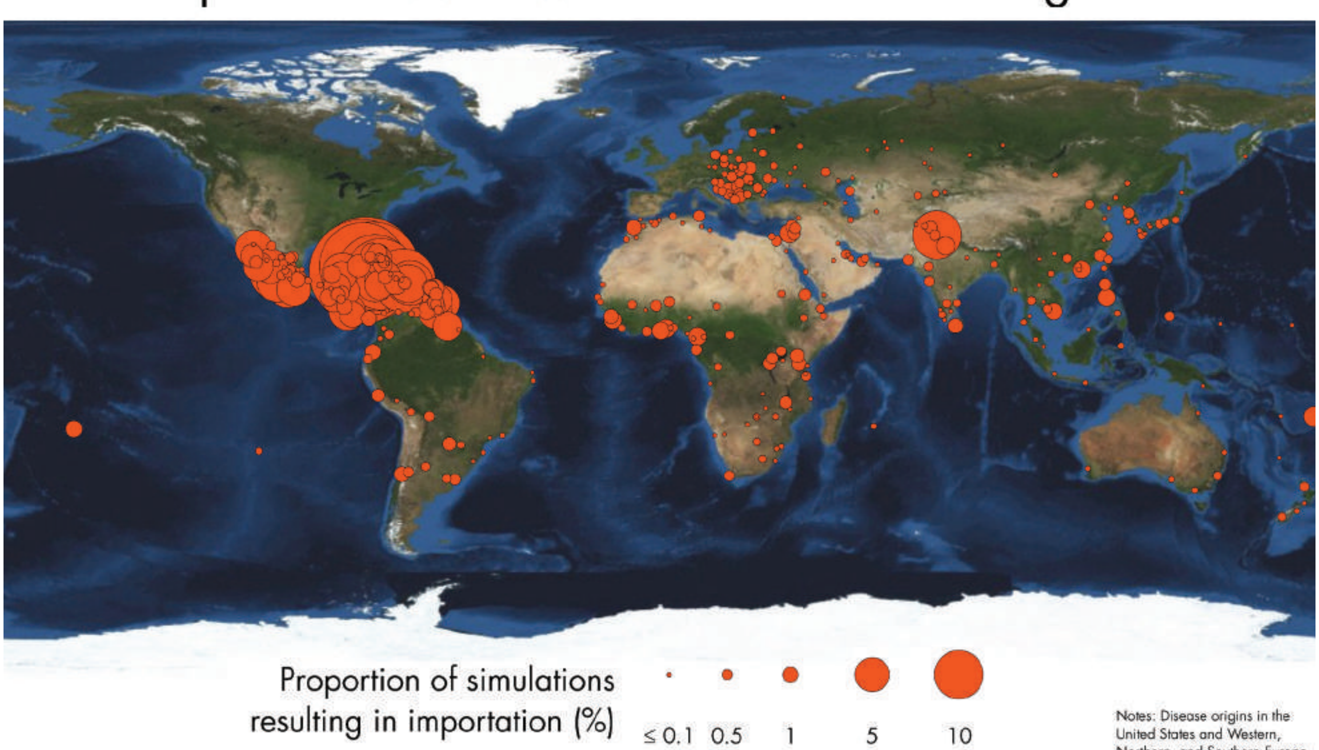
Simulated International Spread of Influenza
Originating in São Paulo



Air Traffic Data Source: International Air Transport Association (IATA) 2007.

Exhibit 93: Web Map

Simulated International Spread of Influenza
From Major Cities Worldwide into Canada during 1st Quarter



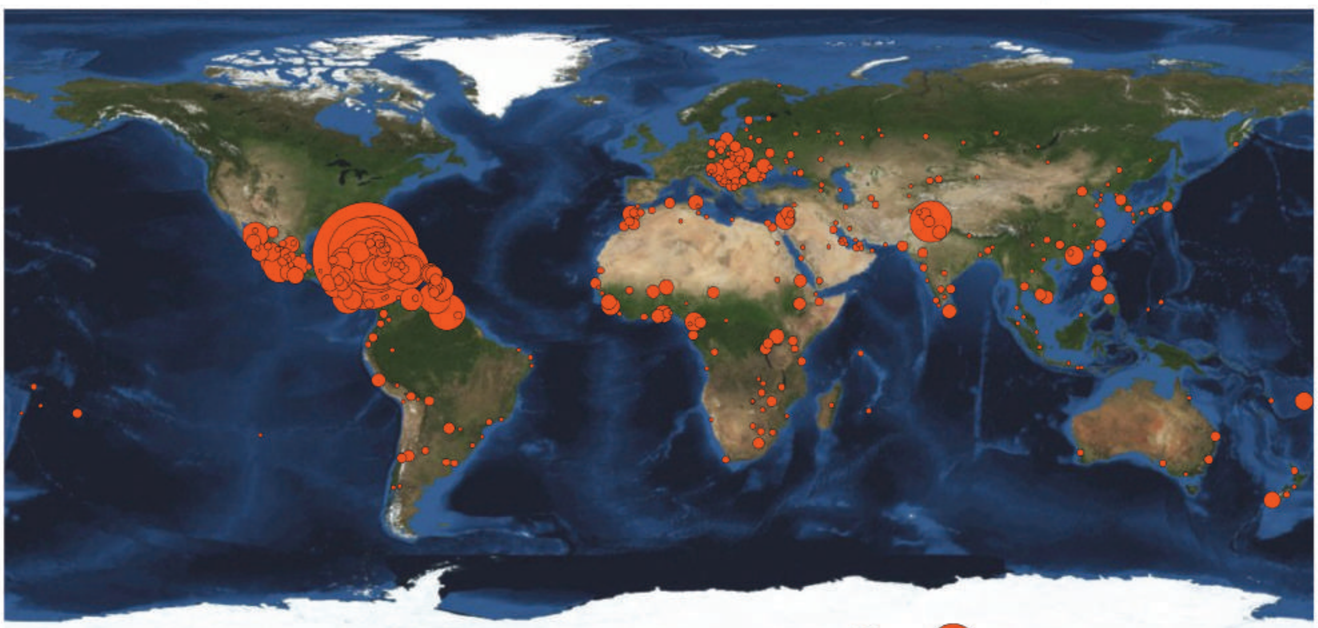
Notes: Disease origins in the United States and Western, Northern, and Southern Europe are not displayed in this map but can be viewed via GIS server.

Air Traffic Data Source: International Air Transport Association (IATA), January through March 2007.

Exhibit 94: Web Map

Simulated International Spread of Influenza

From Major Cities Worldwide into Canada during 2nd Quarter

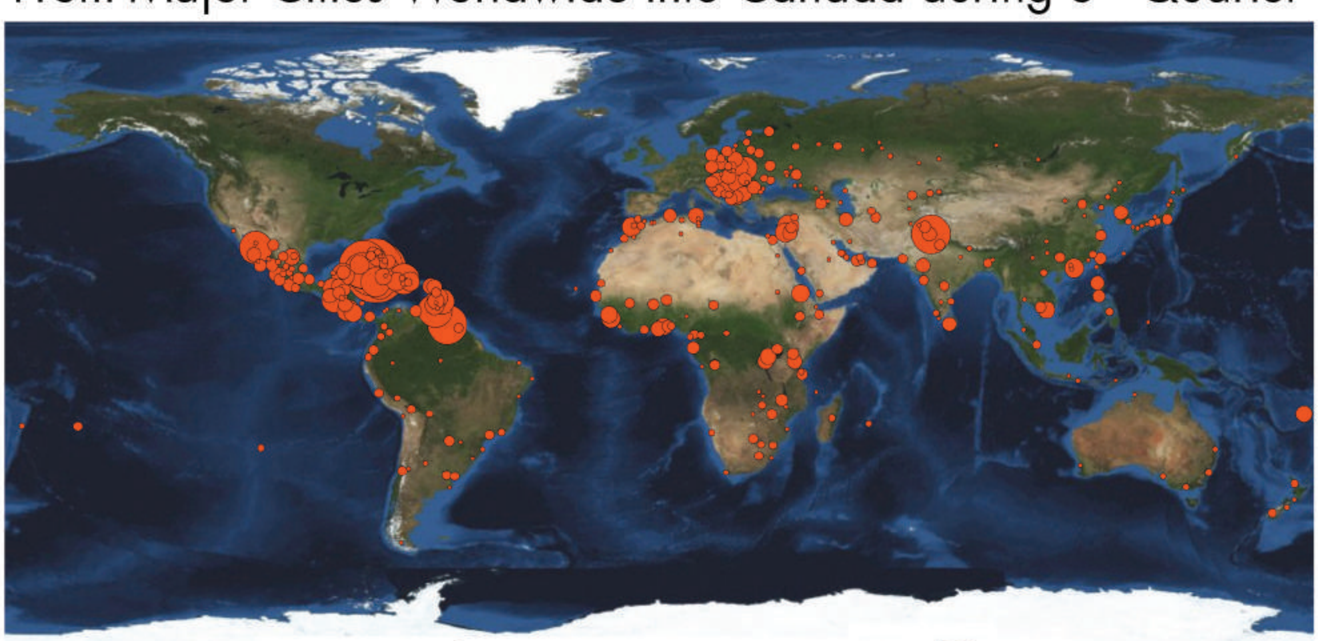


Air Traffic Data Source: International Air Transport Association (IATA), April through June 2007.

Exhibit 95: Web Map

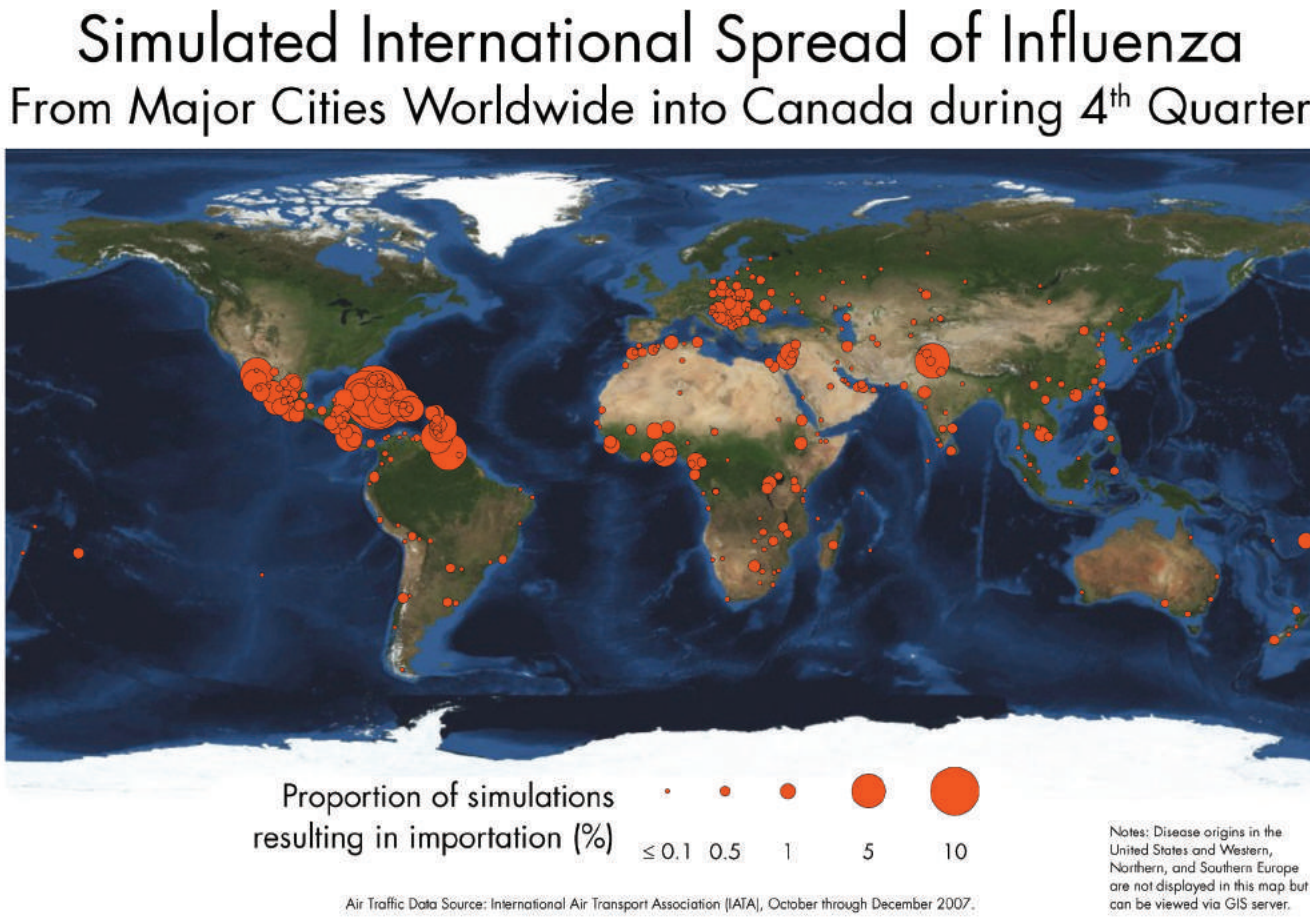
Simulated International Spread of Influenza

From Major Cities Worldwide into Canada during 3rd Quarter

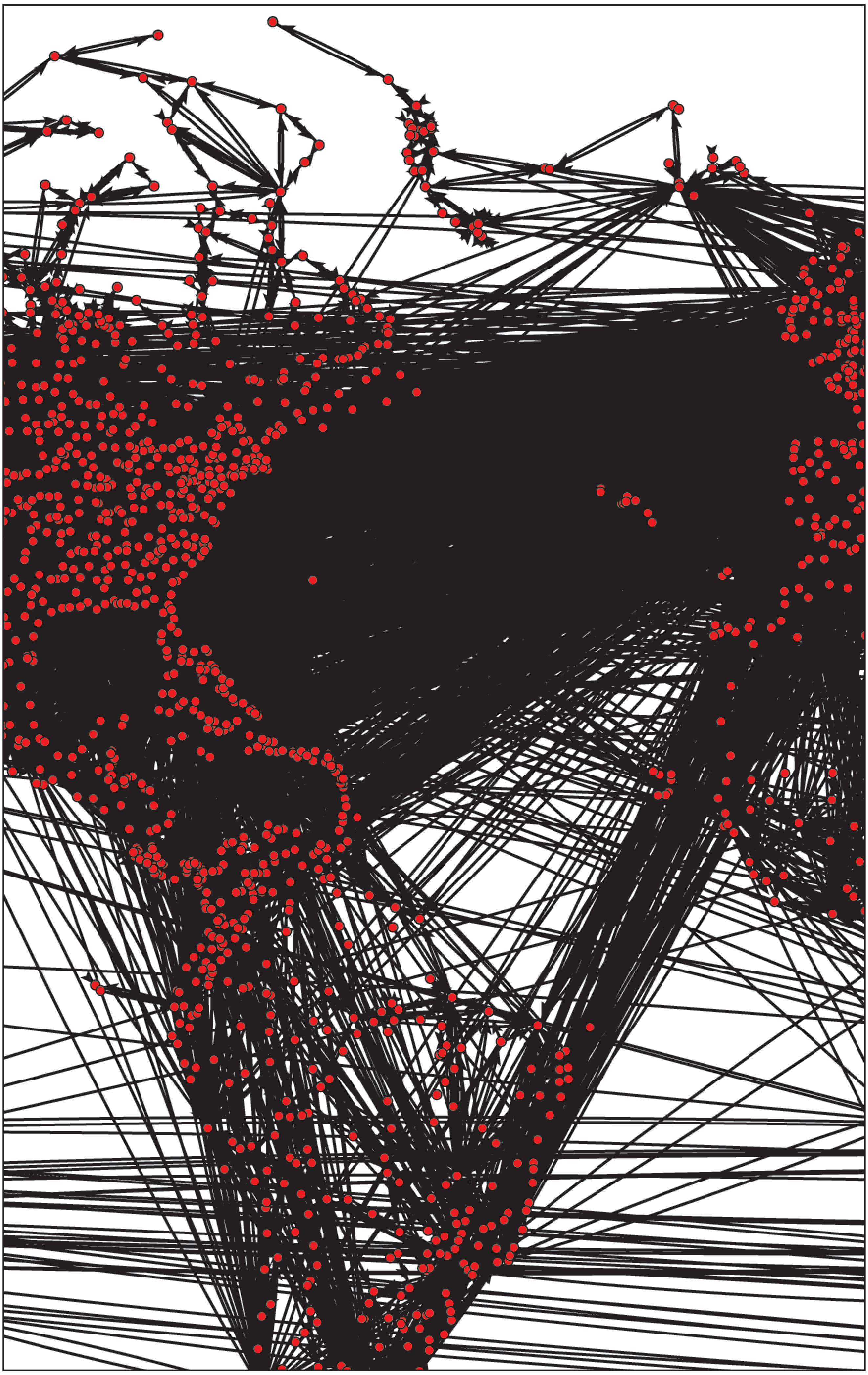


Air Traffic Data Source: International Air Transport Association (IATA), July through September 2007.

Exhibit 96: Web Map



SYNTHESIS AND INTERPRETATION



The global airline transportation network is a dynamic, continuously evolving system of commercial airports and aviation arteries that binds the international community together. While humankind has benefited tremendously from living in an interconnected world, it has become increasingly vulnerable to the international spread of infectious diseases via commercial air travel[1-3]. Although complex, the global airline transportation network has a definable architecture[23] and laws that govern how passengers and commercial aircraft travel through it. Consequently, this transportation system is amenable to study from a global health and security perspective.

The BIO.DIASPORA Project was initiated post-SARS with a goal of improving our understanding of the global airline transportation network and its evolving role as a conduit for the spread of infectious diseases[20]. It has sought to fulfill this objective through the creation of a data warehouse on the world's commercial air traffic patterns and rigorous analysis of these data through the intersection of multiple scientific disciplines including medicine, infectious diseases, public health, health policy, biostatistics, geographic sciences, network analysis, computer sciences, and mathematical modeling. Through applied research, this report: i) characterizes, in unprecedented detail how Canada and the international community are interconnected by the global airline transportation network, ii) considers how Canada's interconnectedness translates into specific vulnerabilities to global infectious disease threats, and iii) identifies strategic measures available to Canada to mitigate its future risks associated with the importation of dangerous infectious diseases.

For global infectious disease threats to breach Canada's borders by air travel, three connected steps must occur. First, an infectious agent must arise internationally; second, the infectious agent must gain access to the global airline transportation network; and third, air traffic departing the source location must transport the agent, directly or indirectly, into a commercial airport within Canada's borders. While factors contributing to the emergence of new or dangerous infectious diseases and measures of a country's ability to detect and control infectious diseases are imprecise, this report provides data on ten crude surrogate markets of disease emergence and control. Its strength however lies in its ability to illustrate how human infectious diseases are capable of spreading through the global airline transportation network and into Canada's borders.

There are three major lines of defence where Canada may direct its efforts in preparing for or responding to imported infectious diseases via air travel. The first line of defence lies at the domestic frontier in Canada's major cities and their associated international airports. The second line of defence lies further upstream in the airline transportation network, at international airports where travelers frequently make flight connections en route to Canada. The third line of defence lies furthest upstream in the international frontier, in cities and countries around the world where infectious diseases may emerge and propagate before finding their way into Canada via air travel. While traditional efforts to address global infectious disease threats have focused predominantly on domestic strategies[24], a more diversified approach aimed at multiple frontiers is likely to be more effective at mitigating Canada's future risks.

On the domestic frontier, most Canadian cities are not centrally (i.e. vulnerably) located within the global airline transportation network. One notable exception is Toronto, which using a number of different metrics, ranks between the 8th and 12th most centrally located cities worldwide. Looking at passenger flows, Toronto receives the highest international traffic volume of any city in Canada – totaling that of both Vancouver and Montreal combined. Within the United States and Canada, Toronto receives the 4th highest volume of international passenger traffic after New York City, Los Angeles, and Miami. Among all cities worldwide, Toronto ranks 24th in international air traffic volumes. These data indicate that among Canadian cities, Toronto is a particularly vulnerable entry point for global infectious disease threats.

Applying most metrics, Vancouver follows as Canada's second most centrally located city in the global airline transportation network, and receives the second highest volume of international passenger arrivals. It bears noting that Vancouver is Canada's most strongly connected city with East Asia, where SARS originated and where many fear the next influenza pandemic will originate. Montreal, as Canada's third most centrally located city within the airline transportation network has international passenger arrival volumes approaching that of Vancouver. However, a greater proportion of Montreal's air traffic originates from Europe, North Africa and the Middle East – areas of the world that are presumably less likely to foster the emergence and propagation of new or dangerous infectious diseases. In addition to being the final destinations of travelers, Canadian cities also operate as important transit points for passengers connecting to other domestic or international locations. Vancouver is the most frequently used transit point in Canada (connecting more than 380,000 international passengers per year) followed closely by Toronto (connecting more than 350,000 international passengers per year) and more distantly by Montreal (connecting 45,000 international passengers per year).

The results of mathematical simulations predicting how influenza is most likely to penetrate Canada's borders are consistent with the outcomes of statistical analyses and network analyses performed in this report. Among the seven different simulated scenarios, Toronto reliably bears the greatest risk of importation, unless the disease threat originates in Hong Kong, in which case Vancouver bears the highest risk. These simulated findings are consistent with empirical observations during SARS, as Vancouver received the greatest number of imported cases of SARS of any city in Canada[6]. Applying different scientific methodologies, the analyses in this report arrive at the same conclusions – Toronto overall is Canada's most vulnerable domestic point of entry for global infectious disease threats, followed by Vancouver, and then Montreal. Domestic efforts to prepare for future infectious disease threats should consider how Canada's major cities are connected with the global community.

As more than sixty percent of passengers traveling to Canada from developing regions of the world use multiple flights to reach their destination, there is a window of opportunity – albeit narrow – to detect and respond to the needs of infected travelers at connecting airports around the world. An important limitation of this approach is that the incubation periods of most infectious agents well exceed the travel times of most international travelers. Consequently, a substantial proportion of travelers harbouring an infectious agent will display no signs or symptoms of illness during the course of their trip through the airline transportation network. Even if travelers are or become symptomatic while traveling, most are unlikely to openly disclose their illness, particularly during emergency settings when such declarations could significantly disrupt their travel plans. While detecting febrile travelers using non-contact infrared thermography is an objective screening method that has been and continues to be used in selected airports around the world, the overall effectiveness of this technology remains unproven[25]. Even if persons are identified as having an elevated surface temperature with infrared thermography, the lack of widely available diagnostic technologies that can then quickly and accurately rule out or confirm the presence of an infectious agent substantially restricts the efficiency of screening passengers during the course of their travels. Nonetheless, it is not essential that interventions directed at this frontier be valued solely on the basis of their ability to detect passengers displaying clinical signs of illness. Targeted public health messages for example, could be directed at travelers in the hope of educating and influencing the behaviours of persons who subsequently become ill. As half of all flight connections made by passengers traveling to Canada from developing areas of the world pass through the airports of just nine cities worldwide, Canada may wish to consider directing some of its preparedness and response efforts to these major transit points. The nine cities include, in order of use as international transit points: i) London, UK, ii) Hong Kong, iii) Tokyo, iv) Frankfurt, v) Paris, vi) Miami, vii) Amsterdam, viii) New York City, and ix) Chicago.

On the international frontier, areas of the world from which global infectious diseases are most likely to enter Canada include those: i) where conditions foster the emergence of dangerous diseases[26] or attract such diseases through travel; ii) which have limited capabilities to rapidly detect and effectively control infectious disease outbreaks should they arise; iii) and which have commercial airports generating high volumes of international air traffic directed toward Canada. This report finds that satisfying the above three criteria is most likely to occur in countries undergoing economic transition, particularly those experiencing accelerated industrialization. Such countries are most likely to have areas that are still developing – with conditions that may foster the emergence of new diseases and have limited resources to detect and control these diseases – adjacent to rapidly industrializing areas that are increasingly well connected with the global community via commercial air travel. Consequently, the conditions required for generating, propagating and subsequently exporting infectious disease threats may all exist within a single country.

Highly industrialized countries may also be very important locations from which infectious disease threats enter Canada, as these countries tend to have well-developed airline transportation systems that place them at heightened risk of disease importation, and potentially, secondary international exportation. Conversely, developing countries with extensive poverty may have conditions that lend themselves to the emergence and local propagation of infectious diseases[27], but typically lack the volume of international air traffic required to rapidly export such diseases to other parts of the world. Thus, infectious disease epidemics in developing countries may either extinguish themselves before spreading internationally via commercial air travel or gradually amplify themselves and increase in their geographic territory until they fall within the catchment area of sufficiently large international airports.

This report identifies thirteen countries around the world – four developing and nine industrialized – as important potential locations from which infectious diseases may enter Canada. The four developing countries are locations where infectious disease threats possess significant potential to enter Canada directly through air travel, while the nine industrialized countries are of greater significance as potential secondary sites for disease exportation. Collectively, the thirteen countries described below generate eighty percent of all international passenger traffic entering Canada from around the world.

While this report has been framed entirely from the perspective of Canada's self-interests, it is important to recognize that the architecture of the global airline transportation network is approximately symmetric, with roughly equal volumes of inbound and outbound international air traffic between city-pairs. Consequently, Canada itself could potentially become an important exporter of emerging infectious diseases as occurred during the worldwide outbreak of SARS[28]. From a contemporary global perspective, the thirteen countries identified in this report are "very close" to Canada with significant potential for the exchange of infectious diseases. Canada may wish to consider initiating or continuing dialogue with the governments of these countries about the shared risks of global infectious disease threats and the potential for shared responsibilities to mitigate these risks. This approach would be consistent with the core principles of the revised International Health Regulations, which aim to direct countries' efforts away from predominantly focusing on passive border control measures, to more active measures aimed at enhancing infectious disease surveillance, detection, and control capabilities around the world[21]. As such, the findings of this report may help Canada protect its own national self-interests through domestic interventions and cooperation with other selected countries worldwide.

Four Developing Economies

China generates the third highest volume of international passenger traffic entering Canada after the United States and the United Kingdom, and the highest volume of any developing country worldwide. Of all international passengers entering Canada today, 4.3% initiate their trip inside China's borders (including Hong Kong). Of the more than 780,000 passengers entering Canada from China every year, 90% originate from three cities – Hong Kong, Beijing, and Shanghai.

China is considered an important potential location from which global infectious disease threats may enter Canada for a number of reasons. Foremost, China's highly accelerated pace of industrialization has created a country of economic extremes. In parts of the country, extensive poverty, high population density, close proximity between humans and animals, a relative deficiency of healthcare resources, and other factors create conditions that may foster the emergence and domestic spread of infectious diseases. At the same time, rapid industrialization has led to shifts in domestic population density from rural to urban areas, such as Hong Kong, Beijing and Shanghai. Today these cities are major global economic engines that are highly developed and continually expanding conduits for international air travel. As such, conditions exist for diseases to emerge, spread domestically, and consequently be exported to other parts of the world. A synergy of factors likely contributed to the worldwide spread of SARS, which originated in Guangdong province before spreading to neighbouring Hong Kong[4,5] – home to the fifth largest international airport in the world. As the world looks to the future threat of pandemic influenza[10], China remains a leading source of human cases of highly pathogenic (H5N1) avian influenza[29]. Of China's metropolises, Hong Kong is most tightly connected to Canada, with nearly 400,000 passengers traveling to Canada each year. To provide a sense of scale, the international volume of traffic entering Canada from Hong Kong alone exceeds the volume of traffic entering Canada from all other cities in Mainland China.

Mexico generates more than 650,000 passenger arrivals into Canada each year – the second highest volume of air traffic from a developing country after China. Of note, a significant majority of air traffic flowing into Canada from Mexico originates from the resort cities of Cancun and Puerto Vallarta during the months of January to April, representing in large part, Canadian travelers returning home from winter and spring vacations. However, Mexico City has a very different pattern of traffic, producing a steady stream of passengers into Canada throughout the year with a surge occurring between the months of June and August. Annually, Mexico City generates nearly 190,000 passenger arrivals into Canada. Poverty, high population density, limited healthcare resources, and high inbound flows of international passengers make Mexico, and particularly Mexico City, a potentially important location from which infectious disease threats may enter Canada.

India is the world's second most populated country after China. With high population density, widespread poverty, and focal areas of accelerated industrialization, India's conditions bear a striking resemblance to those in China. Today, India generates the eighth highest volume of international passenger traffic entering Canada, and the third highest volume from any developing country after China and Mexico. Of all international passengers entering Canada today, 1.8%, or 330,000 persons initiate their trip from inside India's borders. Eighty percent of those passengers originate from just three cities – Delhi, Mumbai, and Amritsar. Although India has experienced serious infectious disease outbreaks in the recent past (e.g. plague), it has not contributed to the international dissemination of such threats[30]. Nonetheless, if India's economy continues to grow at its current pace, its cities will likely become more connected with Canada's over time, thereby increasing potential for the international transfer of emerging infectious diseases.

The Philippines is the fifth largest source of international air traffic into Canada from a developing country, after China, Mexico, India, and Cuba, and the largest source country for skilled workers in Canada today. Although Cuba generates a slightly higher annual volume of international air traffic entering Canada than the Philippines, a significant proportion of Cuba's traffic is generated by Canadian travelers returning home from winter and spring vacations. In this report, the Philippines was deemed a more important potential location for emerging infectious disease threats for the reasons described above; because conditions in the Philippines may be more likely to contribute to the emergence and domestic spread of infectious diseases; and because the Philippines is tightly interconnected with other countries across East Asia – where many experts believe the next influenza pandemic and/or other emerging disease threats will originate.

Nine Industrialized Economies

By a substantial margin, the United States (U.S.) generates the highest volume of international air traffic entering Canada of any country in the world. While the U.S. may be an unlikely source for the emergence of new infectious disease threats, it alone generates over 13% of the world's international air traffic volume and consequently represents a high risk destination for imported infectious diseases itself. Given the extensive population mixing between Canada and the U.S. via the two countries' long contiguous land border and through the high volume of commercial air travel, the U.S. warrants special consideration as an important location from which infectious diseases may enter Canada. With 51% of Canada's commercial air traffic coming from the U.S. and 13% of the U.S.' air traffic coming from Canada, there are compelling reasons for both countries to collaborate on preparing for and responding to global infectious disease threats[31].

The European Union (E.U.) generates almost one-fifth of all international traffic entering Canada. Like the United States, the E.U. may be an unlikely source for the emergence of new infectious disease threats, but it alone generates over 19% of the world's international traffic volume and consequently represents a high risk destination for globally imported infectious diseases. Of E.U. member states, more than 75% of all air traffic into Canada originates from the following five countries in order of volume: i) United Kingdom, ii) France, iii) Germany, iv) Italy and v) the Netherlands. Thus, the E.U. is an important location from which infectious disease threats could enter Canada. Collaboration with the E.U. on shared risks of infectious disease threats would be prudent and could be directed at individual member states that generate a high volume of air traffic into Canada, or more broadly with the E.U. as a collective.

Japan, South Korea, and Taiwan are among East Asia's most highly industrialized economies, collectively generating 3.8% of all international traffic entering Canada. Together, this trio is the fourth largest source of international traffic entering Canada after the United States, the United Kingdom, and China. Although these countries could become primary sources of important emerging infectious disease threats to Canada, of greater concern is their potential to act as secondary exporters of disease after importation from other less developed countries. Given that East Asia may be where the next influenza pandemic emerges and where other important emerging infectious disease threats arise, industrialized economies like Japan, South Korea, and Taiwan appear particularly vulnerable to disease importation. This supposition is consistent with observations during the worldwide outbreak of SARS, when the disease spread quickly and extensively within East Asia[28].

The thirteen countries identified as important potential locations from which infectious disease threats may enter Canada reflect near-present global conditions. All analyses utilized the most current data available at the time of creating this report. Of particular significance, data on the architecture of the airline transportation network and the flows of passengers through it were derived predominantly from 2008 and 2007 data respectively. It bears noting however, the world is continuously changing – countries industrialize, they become more or less connected through air travel, they experience military conflicts, environmental disasters, and subsequent infectious disease outbreaks – each of which may significantly alter the degree of risk to Canada. Consequently, periodic reevaluations of the risk of global infectious disease threats to Canada via commercial air travel are warranted.

Global infectious disease threats are an inevitable part of Canada's future. While some threats may be containable at their source, others will spread and penetrate Canada's borders regardless of all international efforts made to prevent their importation. Consequently, reinforcing domestic lines of defence in high risk Canadian cities and their international airports is an essential part of an overall national biodefence strategy. However, in today's globalized world, the line separating domestic from international infectious disease threats has become increasingly blurred. To address this evolving global reality, Canada will need to increase its efforts to detect and control infectious diseases outside of its national borders, as a way to protect its own vital self interests[32]. Given the narrow window of opportunity to detect infectious diseases in international air travelers coupled with current technological limitations in detecting fever via non-contact infrared thermography[25], Canada may wish to concentrate its efforts in the airline transportation network at selected international airports that operate as major transit points for passengers traveling to Canada. To disrupt, delay, or prevent the entry of global infectious diseases into Canada altogether, increased collaboration with other members of the international community will be required. The findings of this report are intended to guide Canada's preparedness and response efforts to specific vulnerable domestic points of entry, international airports used as major transit points for passengers traveling to Canada, and to international cities and countries with which it is tightly connected as a way to protect its own national self-interests and concurrently strengthen the fabric of global public health security.

REFERENCES

1. World Health Organization. The World Health Report 2007 - A Safer Future: Global Public Health Security in the 21st Century. URL: http://www.who.int/whr/2007/en/index.html. Date of access: April 2009.

2. Knobler S, Mahmoud A, Lemon S, Pray L. Impact of Globalization on Infectious Disease Emergence and Control: Exploring the Consequences and Opportunities. IOM Workshop Summary – Forum on Microbial Threats. National Academies Press, 2006.

3. United States National Intelligence Council. National Intelligence Estimate: The Global Infectious Disease Threat and Its Implications for the United States. Environmental Change & Security Project Report, 2000. URL: http://www.wilsoncenter.org/topics/pubs/Report6-3.pdf Date of access: April 2009.

4. Lee N, Hui D, Wu A, Chan P, Cameron P, Joynt G et al. A major outbreak of severe acute respiratory syndrome in Hong Kong. New England Journal of Medicine 2003; 348(20): 1986-1994.

5. Tsang K, Ho P, Ooi G, Yee W, Wang T, Chan-Yeung M et al. A cluster of cases of severe acute respiratory syndrome in Hong Kong. New England Journal of Medicine 2003; 348(20): 1977-1985.

6. Skowronski D, Petric M, Daly P, Parker R, Bryce E, Doyle P, et al. Coordinated response to SARS, Vancouver, Canada. Emerging Infectious Diseases 2006; 12(1):155-158.

7. Svoboda T, Henry B, Shulman L, Kennedy E, Rea E, Ng W et al. Public health measures to control the spread of the severe acute respiratory syndrome during the outbreak in Toronto. New England Journal of Medicine 2004; 350(23):2352-2361.

8. Poutanen S, Low D, Henry B, Finkelstein S, Rose D, Green K et al. Identification of severe acute respiratory syndrome in Canada. New England Journal of Medicine 2003; 348(20): 1995-2005.

9. Campbell A. The SARS Commission Interim Report: SARS and Public Health in Canada. Appendix E: The Economic Impact of SARS, 2004.URL: http://www.health.gov.on.ca/english/public/pub/ministry_reports/campbell04/campbell04.pdf Date of access: April 2009.

10. Ferguson N, Cummings D, Cauchemez S, Fraser C, Riley S, Meeyai et al. Strategies for containing an emerging influenza pandemic in Southeast Asia. Nature 2005; 437(7056):209-214

11. Meltzer M, Cox N, Fukuda K. The economic impact of pandemic influenza in the United States: priorities for intervention. Emerging Infectious Diseases 1999; 5(5):659-671.

12. Lim M. Global response to pandemic flu: more research needed on a critical front. Health Research Policy and Systems 2006; 4:8.

13. Public Health Agency of Canada. The Canadian Pandemic Influenza Plan for the Health Sector, 2006. URL: http://www.phac-aspc.gc.ca/cpip-pclcpi/ Date of access: April 2009.

14. World Health Organization. World Global Influenza Preparedness Plan, 2005. URL: http://www.who.int/csr/resources/publications/influenza/WHO_CDS_CSR_GIP_2005_5/en/ Date of access: April 2009.

15. Colizza V, Barrat A, Barthelemy M, Vespignani A. Predictability and epidemic pathways in global outbreaks of infectious diseases: the SARS case study. BMC Medicine 2007; 5(34).

16. Brownstein J, Wolfe C, Mandl K. Empirical Evidence for the Effect of Airline Travel on Inter-Regional Influenza Spread in the United States. PLoS Medicine 2006; 3(10):e401.
17. Colizza V, Barrat A, Vespignani A. The role of the airline transportation network in the prediction and predictability of global epidemics. Proceedings of the National Academy of Sciences of the United States of America 2006; 107(7):2015-2020.
18. Hufnagel L, Brockmann D, Geisel T. Forecast and control of epidemics in a globalized world. Proceedings of the National Academy of Sciences of the United States of America 2004; 101(42):15124-15129.
19. Rvachev L, Longini I. A mathematical model for the global spread of influenza. Mathematical Biosciences 1985; 75:3-22.
20. The Bio.Diaspora Project. www.biodiaspora.com
21. World Health Assembly. Revision of the International Health Regulations, 2005. URL: http://apps.who.int/gb/ebwha/pdf_files/WHA58/WHA58_3-en.pdf Date of access: April 2009.
22. Wilson K, von Tigerstrom B, McDougall C. Protecting global health security through the International Health Regulations: requirements and challenges. Canadian Medical Association Journal 2008; 179(1):44-48.
23. Guimera R, Mossa S, Turtschi A, Amaral L. The worldwide air transportation network: Anomalous centrality, community structure, and cities' global roles. Proceedings of the National Academy of Sciences of the United States of America 2005; 102(22):7794-7799.
24. World Health Assembly. International Health Regulations, 1969. URL: http://www.who.int/csr/ihr/ihr1969.pdf Date of access: April 2009.
25. Bitar D, Goubar A, Desenclos J. International travels and fever screening during epidemics: A literature review on the effectiveness and potential use of non-contact infrared thermometers. Eurosurveillance 2009; 14(6).
26. Jones K, Patel N, Levy M, Storeygard A, Balk D, Gittleman J et al. Global trends in emerging infectious diseases. Nature 2008; 451(7181):990-993.
27. Suk J, Lyall C, Tait J. Mapping the future dynamics of disease transmission: risk analysis in the United Kingdom Foresight Programme on the detection and identification of infectious diseases. Eurosurveillance 2008; 13(44).
28. World Health Organization. SARS: How a global epidemic was stopped. Geneva, Switzerland: World Health Organization, 2006.
29. World Health Organization. Avian influenza, 2009. URL: http://www.who.int/csr/disease/avian_influenza/en/ Date of access: April 2009.
30. Centers for Disease Control and Prevention. Human Plague – India, 1994. MMWR 1994; 43(38): 689-91.
31. Security and Prosperity Partnership of North America. North American Plan for Avian and Pandemic Influenza, 2007. URL: http://www.spp-psp.gc.ca/eic/site/spp-psp.nsf/vwapj/pandemic-influenza.pdf/$FILE/pandemic-influenza.pdf Date of access: April 2009.
32. Schwartzman K, Oxlade O, Barr R, Grimard F, Acosta I, Baez J et al. Domestic Returns from Investment in the Control of Tuberculosis in Other Countries. New England Journal of Medicine 2005; 353(10):1008-1020.

TECHNICAL APPENDIX

A. The Markov chain model in each city

Formulating the continuous-time, discrete-state Markov chain is performed from a *time to transition* perspective.

1. First, we define the state by $X(t) = (E(t), I(t))$.
2. Given the state *X(t)* at time *t*, we compute $f = \varepsilon E(t) + (\beta + \gamma) I(t)$.
3. The quantity *f* is the parameter of an exponentially distributed random variable *T* giving the amount of time the process spends in state *X(t)* before making a transition into another state.
4. A number τ is determined at random from T, giving the time of the next transition $t + \tau$.
5. Once the time of the transition is known, the nature of the transition is considered. Thus we determine $\Pr(X(t+\tau) = (e', i') \mid X(t) = (e, i))$, that is, the probability that the new state at time $t + \tau$ is $X(t+\tau) = (E(t+\tau) = e', I(t+\tau) = i')$ given that the state is $X(t) = (E(t) = e, I(t) = i)$ at time *t*, where e, i, e', i' are non-negative integers.

   Given the conceptual SEIR model used:

- The probability that $(e', i') = (e+1, i)$, that is, there is a new infection, is $\beta i / f$.
- The probability that $(e', i') = (e-1, i+1)$, that is, an exposed individual becomes infectious, is $\varepsilon e / f$.
- The probability that $(e', i') = (e, i-1)$, that is, an infectious individual is removed from the infectious class due to recovery with immunity or death, is $\gamma i / f$.
- Note that these three probabilities add up to 1.

6. Once in this new state, the process repeats from step 1, using the new time $t + \tau$ and the new state $X(t + \tau)$ as the given state.

B. The metapopulation model

To consider the interaction of cities through the global airline transportation network we use a metapopulation framework. For this, two steps are performed:

1. Each city is uniquely identified using three letter city codes from the International Air Transport Association (IATA).

2. The nature of interactions between cities is precisely defined using worldwide, true origin and destination, flight passenger data from the year 2007. We introduce the notation m_{ab}^{S} to describe a metric of passenger flows from city *a* to city *b* for individuals in state *S=E* or *I*. Note that we allow for the *possibility* that the metric of passenger flows between cities depends upon the epidemiologic status of individuals (i.e. infectious individuals may be less likely to travel than others). This allows us to model, for example, the potential impact of exit screening of infectious individuals at commercial airports or the effects of pathogen virulence on the ability of passengers to travel. In this analysis, it is assumed that there are no effective measures in place to prohibit travelers from boarding commercial aircraft and consequently infectious individuals are assumed to travel with equal probability to all others.

C. The Markov chain model for a global network of cities

The Markov chain model follows the single city template, but now, the transportation of individuals from one city to another is added.

1. We now define the state by $X(t) = (E_1(t), I_1(t), \ldots, E_N(t), I_N(t))$.

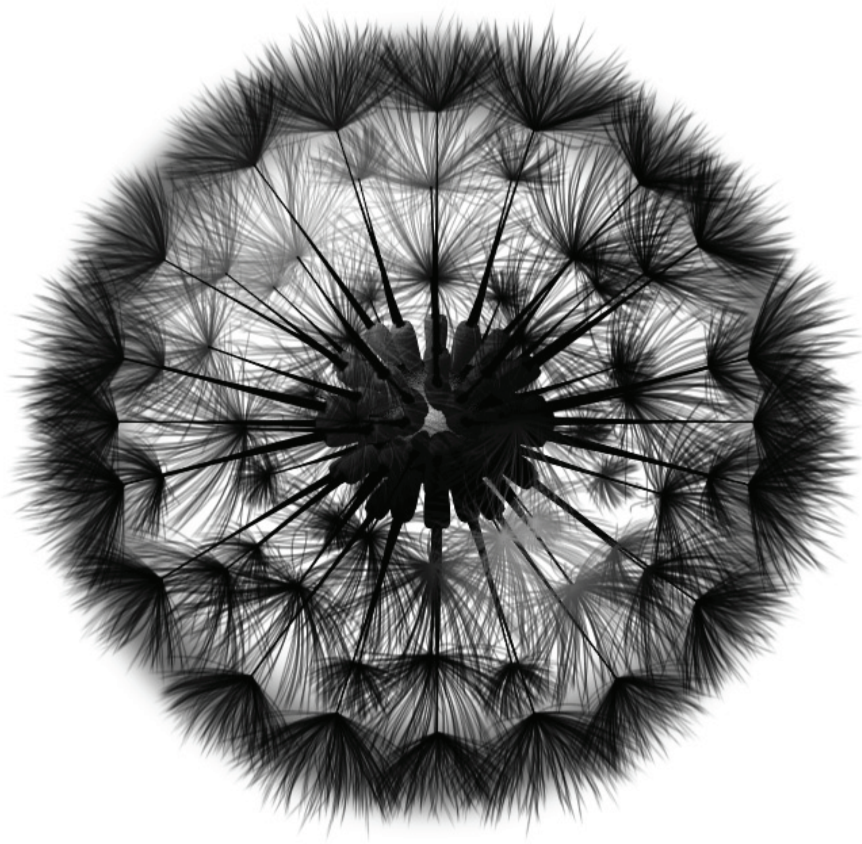
2. At time *t*, we follow the single city template, with the following modifications:

- The exponential distribution determining the time to the next transition has parameter $f_t = \sum_{a=1}^{N} \left(\varepsilon_a E_a(t) + (\beta_a + \gamma_a) I_a(t) \right) + \sum_{\substack{a,b=1 \\ a \neq b}}^{N} \left(m_{ab}^E E_a(t) + m_{ab}^I I_a(t) \right)$.

3. There are more potential outcomes. Given a state at time *t* of the form $X(t) = \left(E_1(t) = e_1, I_1(t) = i_1, \ldots, E_N(t) = e_N, I_N(t) = i_N \right)$, the probability $\Pr\left(X(t+\tau) \mid X(t) \right)$ that state $X(t+\tau)$ takes the form $X(t+\tau) = \left(e_1', i_1', \ldots, e_N', i_N' \right)$ after the transition that occurs at time $t+\tau$ is given by the following.

- The probability that $\left(e_1', i_1', \ldots, e_a', i_a', \ldots, e_N', i_N' \right) = (e_1, i_1, \ldots, e_a + 1, i_a, \ldots, e_N, i_N)$, that is, there is a new infection in city *a*, is $\beta_a i_a / f_t$.
- The probability that $\left(e_1', i_1', \ldots, e_a', i_a', \ldots, e_N', i_N' \right) = (e_1, i_1, \ldots, e_a - 1, i_a + 1, \ldots, e_N, i_N)$, that is, an exposed individual becomes infectious in city *a*, is $\varepsilon_a e_a / f_t$.
- The probability that $\left(e_1', i_1', \ldots, e_a', i_a', \ldots, e_N', i_N' \right) = (e_1, i_1, \ldots, e_a, i_a - 1, \ldots, e_N, i_N)$, that is, an infectious individual is removed from the infectious class due to recovery with immunity or death in city *a*, is $\gamma_a i_a / f_t$.
- The probability that $\left(e_1', i_1', \ldots, e_a', i_a', \ldots, e_b', i_b', \ldots, e_N', i_N' \right) = (e_1, i_1, \ldots, e_a - 1, i_a, \ldots, e_b + 1, i_b, \ldots, e_N, i_N)$, that is, an exposed individual from city *a* travels to city *b*, is $m_{ab} e_a / f_t$.
- The probability that $\left(e_1', i_1', \ldots, e_a', i_a', \ldots, e_b', i_b', \ldots, e_N', i_N' \right) = (e_1, i_1, \ldots, e_a - 1, i_a, \ldots, e_b + 1, i_b, \ldots, e_N, i_N)$, that is, an infectious individual from city *a* travels to city *b*, is $m_{ab} i_a / f_t$.
- Note that these probabilities add up to 1.

Student Acknowledgement



2009