

SPATIO-TEMPORAL VISUALIZATION OF THE INFLUENZA A (H1N1) PANDEMIC

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ABSTRACT

This paper focuses on multiple visualization techniques for mapping pandemics with respect to space and time. With the use of maps and other statistical information, a link between the spread of Influenza A(H1N1) and international air travel follows from the Bio.Diaspora Project [2]. The study area for this project focuses on North America, specifically Canada and the United States. However, the spread of the disease is worldwide. Worldwide trends, as well as trends in the Western Hemisphere were taken into consideration. The methodology behind this project is complex as the geographic region examined is vast. With data coming from a variety of sources multiple assumptions were made. The assumptions used lead to different visualization techniques.

KEYWORDS: Pandemics, Influenza A(H1N1), Visualization.

INTRODUCTION

The spatial and temporal dimensions play an important role when dealing with pandemics. Influenza A(H1N1) is no exception. Cases of Influenza A(H1N1) during reporting periods were defined as people with Influenza-Like-Illness (ILI) with symptoms of a temperature of 100°F and a cough or sore throat [1]. Confirmed cases of Influenza A(H1N1) had two components which included a real-time reverse transcription polymerase chain reaction (RT-PCR) and a viral culture [1].

On March 18th, 2009, the Mexican government started tracking an increase in severe respiratory illnesses [1]. This increase in illnesses led to testing, which confirmed that a new strain of influenza was present in Mexico. This strain is referred to as Influenza A(H1N1) or H1N1 for short. In mid April, the US and Canada both started reporting cases of the Influenza A(H1N1) virus. On April 29th, 2009, World Health Organization (WHO) declared a Phase 5 Pandemic. The peak pandemic phase, a Phase 6 Pandemic, was declared for Influenza A(H1N1) on June 11th, 2009.

The World Health Organization (WHO) increases its pandemic phase ranking based on spread and not severity of the disease. There are 6 pandemic phases followed by a post-peak and post-pandemic categorization. A breakdown of the pandemic levels and their descriptions are shown in Table 1.

Table 1: World Health Organization Pandemic Levels Breakdown

Pandemic Phase	Description
Phase 1	A circulating virus in animals has no reported human cases
Phase 2	A circulating virus in animals has caused human infection
Phase 3	A small cluster of people in a community-level outbreak contract the infection but has not resulted in human-to-human transmission.
Phase 4	As well as animal-to-human transmission, human-to-human transmission has occurred.
Phase 5	Human-to-human spread of the virus in a minimum of 2 countries in a WHO Region. Declared on April 29th, 2009
Phase 6	Criteria in Phase 5 and a community level outbreak in at least one other country in a different WHO Region. Declared on June 11th, 2009
Post-Peak Phase	Countries with adequate surveillance have disease levels drop below peak values.
Post-Pandemic Phase	Influenza disease levels return to normally observed seasonal levels.

Dr. Margaret Chan, Director General of the WHO, released a statement on June 11th, 2009 about the pandemic decision. In Dr. Chan's address she stated: "Globally, we have good reason to believe that this pandemic, at least in its early days, will be of moderate severity. As we know from experience, severity can vary, depending on many factors, from one country to another." [1].

GIS Modelling

The geospatial modelling of a pandemic virus allows for trends involving location to emerge through spatio-temporal visualization. The modelling of the outbreak in this report focuses on the number of cumulative cases over time. Since Influenza A(H1N1) is a pandemic of moderate severity, the number of deaths was not significant enough at the time of data collection to create a visualization model. The importance of visualizing the number of cases is to aid in determining the clusters of cases. Visualization shows differences in severity and variations based on geographic region.

The recently published Bio.Diaspora project, by St. Michael's Hospital in Toronto, Canada, involved volumes of international air travel and the spread of Influenza A(H5N1), also known as avian flu. This project focused mostly on case counts in quarters and international flight patterns between countries [2]. The project specifically looked at number of cases nationally, as well as pig density, population, economic standing and healthcare factors [2]. The St. Michael's project was used as an outline to the research presented here, with an emphasis on the geographic scale of analysis. Less significance was placed on other external factors because of the small variation of factors in Canada and the US at a national level.

The Time Factor

In this model of Influenza A(H1N1), the virus was in its early stages. Time as a factor played a crucial role in monitoring the virus. Eventually, the speed at which the virus circulated, forced WHO to change its reporting standards on Influenza A(H1N1) [1].

It is obvious that over time the cumulative number of cases will always be increasing. The concern is the rate at which the number of cases is increasing. Also, with the lack of statistics on recovered patients, it is impossible to tell at any given time how many people are infected with the virus.

A number of factors could be integrated into a model for Influenza A(H1N1). Some examples of the factors that could be related to the spread of an infectious disease include age, sex, medical history, population, density, and economic conditions. However, these particular factors will not be discussed in this paper.

Objectives

The area of focus of the research presented here is limited to North and Central America at a national level due to time, quantity of data and analysis constraints. In Canada and the United States of America, provincial and state breakdown is provided for analysis also. In addition, Canada has a geographic breakdown by District Health Areas (DHAs) and the US has a county level breakdown of cases. The varying levels of scale provided an insight into significant locations in clusters. This paper attempts to address the question of how GIS can be used for modelling,

tracking, and visualization of reported Influenza A(H1N1) cases. The specific objectives of this research are to: a) Visually report H1N1 cases, b) Show the dispersion of H1N1 cases over time.

METHODOLOGY

Data Collection

The methodology for the data collection and analysis of Influenza A(H1N1) required many different methods and exceptions in order to produce accurate results.

Spatial data collection consisted of cumulative case numbers, locations and dates. Data was collected for multiple levels of government throughout North and Central America. The original data was collected from the World Health Organization (WHO) which provided case counts for countries worldwide [1]. This data was then segregated to highlight Canada, the US, Mexico and other Central American countries. The Pan Americas Health Organization (PAHO) is a member of the WHO Regions that focuses on North, South and Central America [3]. This provided accurate case counts for countries throughout North and Central America.

Within Canada and the US, federal government agencies collected state and provincial case counts. The Centre for Disease Control (CDC), in the US, provided a case breakdown at the state level [4]. The Public Health Agency of Canada (PHAC) provided a breakdown for the provinces and territories in Canada [5]. The final sources for data collection were from provincial and state government health departments [6-56]. In terms of time accurate data, a delay in case numbers was noticeable for WHO reported values. The delay occurs because each level of government has a subset of geographic regions reporting to it. The process of reporting is shown in Figure 1.

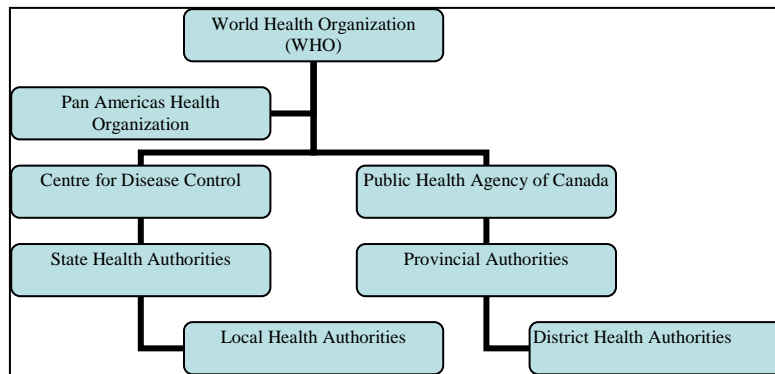


Figure 1. Reporting Agencies Structure.

Other spatial data that was collected related to population, size and income. This data was extracted from ESRI Data & Maps 9 and ESRI Data & Maps 9.3. All geographic data were in vector form, as either polygons or points. A more detailed description of how geographic information is provided in section 4.

Non-spatial data consisted of news reports and briefings referring to populations of infected individuals, reporting periods, pandemic phase updates and progress on a vaccine. These updates came from the spatial data sources listed above, as well as news agencies such as The Canadian Associated Press, Canadian Television Online, as well as online professional networking data sources, such as the LinkedIn H1N1 Alliance Group.

Data Analysis

In order to understand the spread of Influenza A (H1N1), geographic visual trends were analyzed. This was done using geospatial data provided.

The use of statistical analysis included investigating the mean, variance, standard deviation, range and Normal QQ (Quantile-Quantile) plots. This analysis was completed on the national level in North and Central America, including state and provincial analysis for the US and Canada. This level of analysis was also done for areas of interest, which will be discussed in further detail in Results.

The visualization of variables is represented graphically in a variety of charts and graphs. The geographic visualization is discussed in further detail in Geovisualization.

Data that is affected by factors requires assumptions to maintain a level of consistency for results. All time series data must be represented using a unique time frame. With an assortment of agencies reporting case numbers, reporting periods varied. To rectify this problem, dates were chosen for reporting periods based on a weekly schedule, unless otherwise noted. The data that fell closest to the end date of the week period, without passing the reporting period end date, was used to represent that week. If there was no reported date provided within the week, another set of assumptions were required. The assumptions used for areas that did not have values in a time period are the “No Data Assumption”, “Interpolation Data Assumption” and “Homogeneous Data Assumption” “No Data Assumption” was used if data was not available for a specific time period. This geographic area was assigned a value of -1. Data would be visually excluded in geographic representations. More on this will be discussed in Geovisualization. “Interpolation Data Assumption” was only used if a reporting period before and after a missing reported period had values. When interpolating the mean between the two reporting periods was used. The median date was used as the reporting day to determine what reporting period the data was specified for.

Homogeneous Data Assumption

“Homogeneous Data Assumption” assigned a constant value to all geographic districts in a region. As a result the use of this assumption would be if a state did not provide a county breakdown of cases, the state count was assigned to all counties. Misleading results can occur; therefore, a visualization technique needs to be developed. Again, this will be discussed in section 4. A subsection of the “Homogeneous Data Assumption” is the “District Data Assumption”

District Data Assumption

“District Data Assumption” is a subset of the Homogeneous Data Assumption. The assumption was used to assign values when cases were reported for districts instead of counties or DHAs. In all areas where districts were reported, the breakdown by county or DHAs was available. For example, if a state is split into North, South, East and West districts, all states within the North district are assigned the same case value. The state of Minnesota divided its counties into 8 regions, which is illustrated in Figure 3. Figure 3 shows the 8 regions of Minnesota which were quantified by regional case numbers.

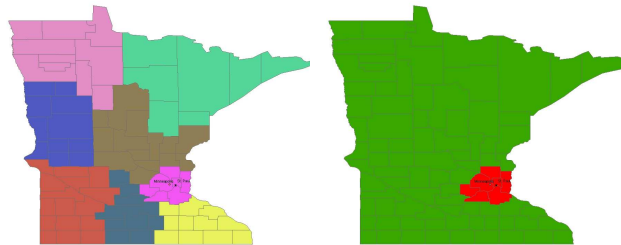


Figure 3. District Data Assumption Minnesota Regions assigned homogeneous values within the Region.

GEOVISUALIZATION

Background

Geo-temporal visualization is the process of exploiting different spatial and attribute data sources for constructing time-series visual models for specific geographic phenomena. All visualization techniques adopted in this project were using ESRI ArcGIS and Microsoft Excel. Visualizations were created over time using continuous streaming and animated maps.

Geovisualization was used as the preferred method for analysis as a lack of trends appeared in non-spatial data. In the early stages of Influenza A(H1N1), results were sparse in terms of population, size, density and economic standing. This led to the realization that the geographic location must bear some weight in disease spread. Other geographic trends might emerge with large public transit systems, international airports or by proximity to each other over time. The factor of time was also considered when using geovisualization and the effect that time has on cumulative number of cases in an area.

In this project, cases were represented in polygon form for a country, state, province, county or DHA. Canada and the United States of America provided a county or DHA breakdown. Central American countries, such as

Mexico and Puerto Rico, are represented as polygons with case values for the whole country. Apart from Mexico, the breakdown remained at the country level because the overall size and number of cases in Central American countries are relatively small in comparison to Canada, Mexico and the US.

Significance

This report summarizes an effort addressing a unique event that devastates humanity worldwide. The scope of the project is complicated and addresses multiple geographic breakdowns, while integrates large amount of data.

While examining the data related to Influenza A (H1N1) cases, many problems arose. The spatial extent of the project, although viewed at the county and DHA level, could be shown in an even smaller extent. In many areas in Canada the district health area is still rather large; this makes it difficult to geographically refine the source of spread in an area. With an improved spatial extent, cases may be represented as smaller vector features. These features could include a smaller polygon or point form. This would lead to improved accuracy of locating the centre of H1N1 spread within a region. This research has an immense amount of factors that could affect the spread; factors such as population, age, sex, medical history, and environment play a vital role in the spread of H1N1.

Finally, the spread of infectious disease does not discriminate. Although we can quantify factors that put an individual at risk, it does not exclude the rest of the population from coming in contact with the disease. An account for randomness should be taken into consideration, as well as the exclusion of outliers. Not every case will be able to be explained by factors outlined by a statistical model.

RESULTS

Worldwide

In March 2009, the Mexican government noticed an increase in severe respiratory illnesses. The respiratory illness was identified as a new strain of influenza, known as Influenza A(H1N1). Cases then spread to the United States of America and Canada. The worldwide cumulative number of cases is represented as an increasing function over time. Although the cumulative death toll is an increasing function over time as well, the percentage of deaths from H1N1 is a decreasing function. An increase of occurrences of the virus does not imply an increased chance of death in this case. The increase in cumulative cases could be categorized into three periods. In the early days of the virus, the rate at which people were contracting the virus was low. The rate continued to increase in the next two periods. Finally, in the US, Mexico and Canada, at any given time in the study period, at least 55% of all reported cases were located in the three countries mentioned.

On June 11th, 2009, a Phase 6 Pandemic was declared by the WHO. A Phase 6 Pandemic is defined as a virus that is circulating in at least 3 countries in 2 WHO Regions. It has been speculated by many that the WHO delayed in declaring a Phase 6 Pandemic, since it is present in over 70 countries worldwide [1].

North America

The virus has had a strong presence in North America. From the first recognition of H1N1, North America has accounted for more than 75% of all cases in the Pan Americas WHO Region and over 55% worldwide. Comparing North, Central and South America, a vast majority of cases were in North America. North American cumulative cases and percentage of deaths showed the same general trend as at the worldwide level. This should be intuitive as the majority of cases were in North America. The rate of increase followed a similar trend when compared to the worldwide data, except during the intermediate period, which showed a decrease in the rate of spread. This could possibly be due to awareness level at the time. However, after this period, a Pandemic Phase 6 was called, which produced an increase in case volumes.

A look into Central America showed that and the data generally followed a similar pattern as the worldwide data. This included the rate increase analysis; however, the number of cases is much smaller in Central America when compared to North America and the world.

Canada

The H1N1 virus was first recognized in Mexico and quickly spread to the US and Canada. This is an immense concern for Canada. As most transfers of the disease were human-to-human contact, an analysis of how people move between the countries must be examined.

Canada has six major access points for international air travel: Toronto, Vancouver, Montreal, Calgary, Ottawa, and Halifax (Figure 4). When flying into these six Canadian access points, 54.6% of international air travel

originated from the US and Mexico. Canada's six international entry points and their volume of passengers from North and Central America, categorized by direct and indirect flights, are shown in Table 2. It is obvious from Table 2 that the number of cumulative H1N1 cases corresponds to the volume of North and Central American direct and indirect flights. An exception to this pattern is Vancouver. The change over time in cumulative cases for Canada, by DHAs is represented in Figure 5.

An odd note about Canada is that over time, the percentage of death increased during the study period. This increase in deaths is unexplainable at this time due to privacy issues concerning those infected with the virus. However, factors that may contribute to the increase in the number of deaths are age, sex, heritage or location.

Table 2: Canada's 6 International Entry Points and Volumes of Traffic

CITY	H1N1 CASES (July 2009)	NA DIRECT	NA INDIRECT	CA DIRECT	CA INDIRECT
Toronto	1494	2,341,415	782,354	535,240	173,332
Montreal	1096	726,978	511,553	176,275	135,951
Calgary	415	480,956	458,216	49,823	96,903
Ottawa	348	160,508	315,436	17,371	40,217
Halifax	177	63,072	157,233	17,283	16,754
Vancouver	81	1,117,787	723,007	62,495	131,715

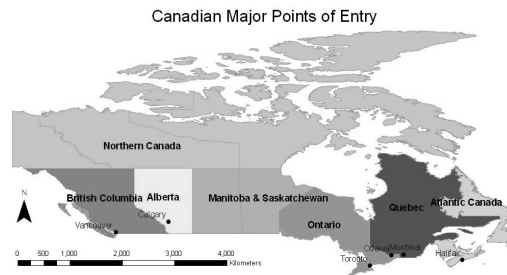


Figure 4. Canadian Major Points of Entry.

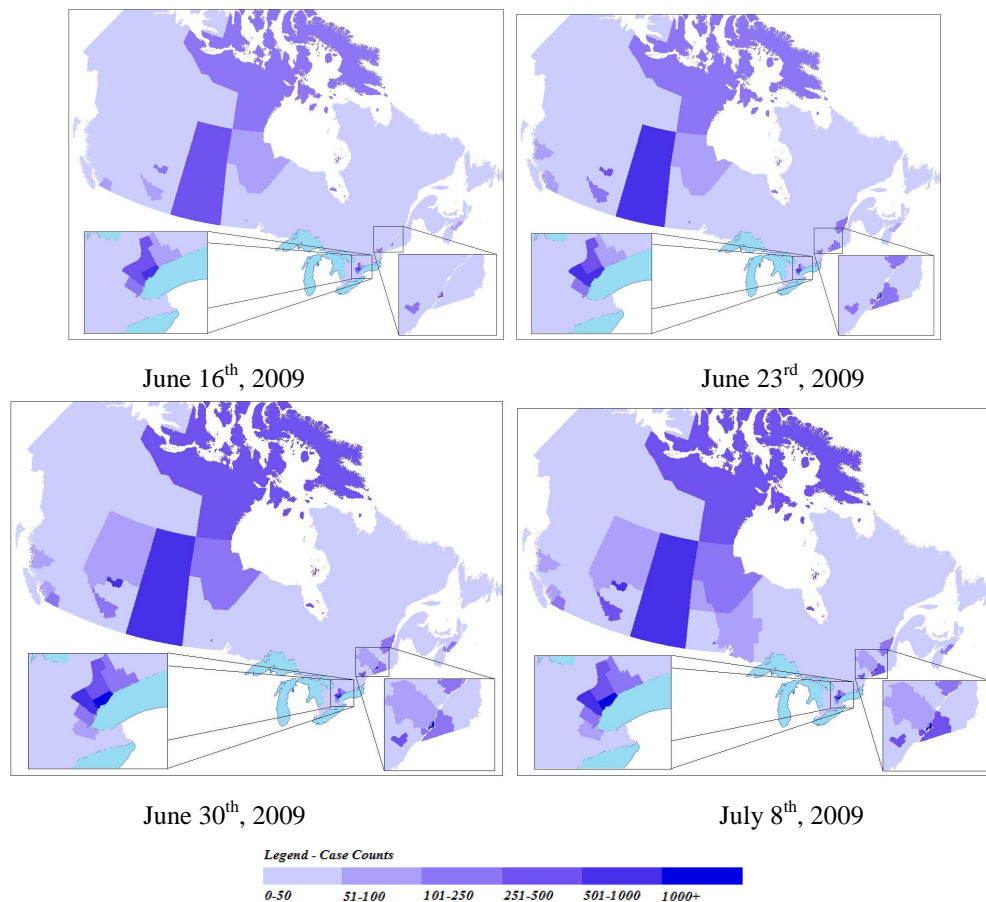


Figure 5.: Canadian Cumulative Cases by District Health Area.

United States of America

The United States of America shares a border line with Mexico and Canada. Considering the majority of cases were present in these three North American countries, the geographic proximity to Canada and Mexico is a cause for concern. The percentage of death in the US is to be noted. The death rate continually decreased until May 15th, 2009, and then increased to approximately half the level of the percentage of deaths in the early stages. The increase continues as time passes but never reaches the initial peak value.

When looking at cumulative case counts in the US, the top 10 states for high case volumes had over 1000 cases for the last 3 reporting periods available. The top 10 states with H1N1 cases are: Wisconsin, Texas, Illinois, California, New York, Florida, Pennsylvania, Connecticut, New Jersey and Massachusetts. Another reporting period for the week of July 17-24 was available, however, it is only represented visually, as many government bodies recently decided to stop recording case tallies. Table 3 shows the top 10 states and the cumulative case values for the available reporting periods in June and July. An illustration of the 50 states and the District of Columbia's cumulative case counts is shown in Figures 6.

Table 3: Top 10 States with H1N1 Cases and corresponding case counts

STATE	JULY 17	JULY 10	JULY 2	JUNE 25	JUNE 19
Wisconsin	6031	6031	5861	4273	3008
Texas	4975	4463	3991	2981	2519
Illinois	3357	3259	3166	2875	2526
California	3161	2461	1985	1492	1245
New York	2670	2582	2499	2272	1300
Florida	2188	1781	1302	941	562
Pennsylvania	1914	1794	1748	1483	942
Connecticut	1581	1364	1247	877	767
New Jersey	1350	1289	1159	899	603
Massachusetts	1343	1328	1308	1287	1270

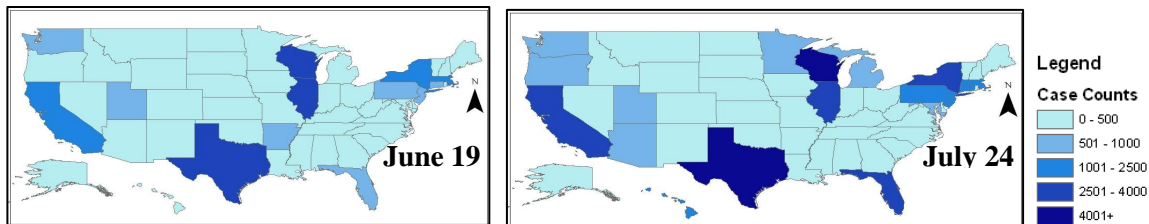


Figure 6. United States of America Cumulative Cases by State.

The Bio.Diaspora project [2], examined major transit centres and avian flu, and identified the Top 20 International Transit Centres worldwide. Of the 20 International Transit Centres, 7 are located, in 5 states, within the continental US. These 7 transit centres are New York, Atlanta, Chicago, Miami, Houston, Los Angeles and Dallas/Fort Worth. These airports are listed in Table 4, with the number of passengers arriving in a year. The data presented forces the question: does the existence of an international transit centre affect the number of cases in the county that the airport is located in?

In the US, a breakdown of the county cases was analyzed. An analysis was done for all states but focused on the 10 states listed above. The county case count is illustrated in Figure 7. In Figure 7, the “No Data Assumption” was used in order to visualize an accurate case breakdown. It should be noted that all the International Transit Centres in the US, except for Atlanta, are located in the top 10 states for cumulative H1N1 cases. More specifically, the H1N1 cases are located in the top 6 states. When examining the location of the airports at the county extent, it becomes obvious, that in general, the county that has the highest number of cases within the state is where the airport is geographically located. Also, the amount of cases decreases as the distance from the airport increases. The county views of the International Transit Centres with H1N1 cases are exemplified in Figures 8-11. As earlier mentioned, Atlanta’s airport does not follow the trend of severity presented. Additionally, Florida, which is where Miami International Airport is located, did not provide a county breakdown of H1N1 cases.

Table 4: 7 International Airports (with ranking) in the US that belong to the Top 20 Worldwide Transit Centres

AIRPORT	RANK OF INT. TRANSIT CENTRE	STATE	# OF H1N1 CASES 07.17.09	# OF PASSENGERS
New York (John F. Kennedy)	6	New York	2670	13,288,444
Atlanta	7	Georgia	174	1,260,044
Chicago (Chicago O'Hare)	8	Illinois	3357	2,773,816
Miami	13	Florida	2188	5,279,146
Houston	14	Texas	4975	1,543,176
Los Angeles	17	California	3161	6,513,855
Dallas/Fort Worth	20	Texas	4975	Not Available

Note: Passenger volumes do not include traffic between Canada and the US.

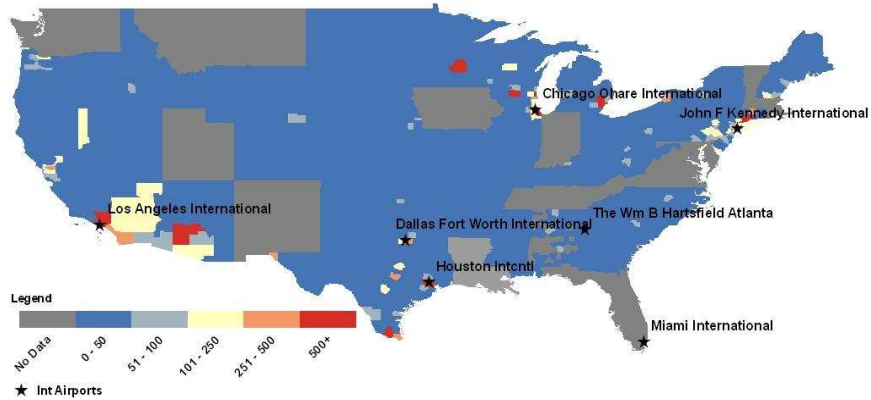


Figure 7. United States of America Cumulative Cases by County.



Figure 8. Chicago, Illinois
Chicago O'Hare Intl. Airport

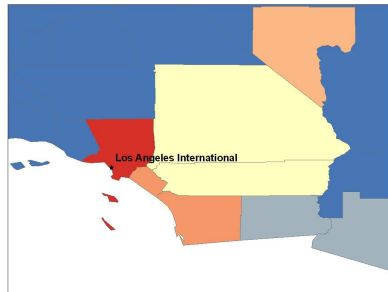


Figure 9. Los Angeles, California
(L.A. Intl. Airport)

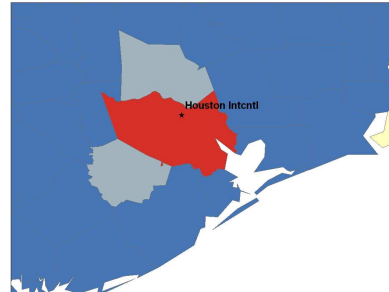


Figure 10. Houston, Texas
Houston Intercontinental

Finally, the 4 states that compose the bottom of the top 10 with H1N1 cases are Pennsylvania, Connecticut, New Jersey and Massachusetts. The State of Massachusetts did not provide a county breakdown on H1N1 cases. Pennsylvania, Connecticut, and New Jersey are close in geographical proximity compared to other states across the US. Visually, for the State of New Jersey, the counties with the highest cumulative case counts are the counties that are the closest in proximity to the State of New York. Also, the counties in New Jersey are geographically adjacent to New York City, where John F. Kennedy International Airport is located. An overall view of Pennsylvania, Connecticut, New Jersey and New York is provided in Figure 12.

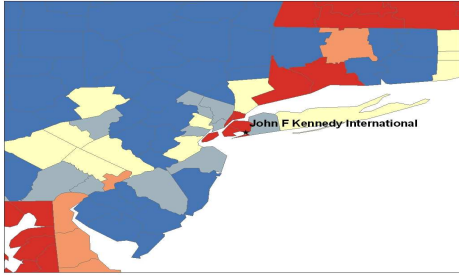


Figure 11. Dallas/Fort Worth, Texas
Dallas/Fort Worth International Airport

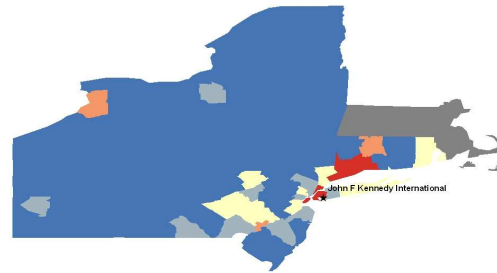


Figure 12. Pennsylvania, Connecticut, New Jersey
and New York County Breakdown

It would seem that in the early stages, the location of an international airport contributes to the number of Influenza A(H1N1) cases a county has. Numerous other factors contribute to the spread of an infectious disease, which could include the population density of the county where the airport is located. Examining the population density of all counties and number of cases could lead to another relationship of spread. However, at the state and provincial level, the relationship between population density and number of cumulative cases is lacking strong statistical evidence.

CONCLUSION & RECOMMENDATIONS

When dealing with a project that concerns a population's safety, many improvements can be made to increase the accuracy of information presented. The next step in this research is a geographic breakdown on a smaller scale, such as by postal code, which would increase the accuracy of areas with outbreaks. This information was not available for this project and would require a high level of security clearance. Dealing with near to exact locations of infected individuals raises privacy issues, which must be addressed.

Other areas that could be pursued with modelling infectious diseases would be regression modelling on climate, population, density, age and sex of infected, volume of various types of traffic and social economic measures. Although, some of this has been done by the Bio.Diaspora Project [2] on a worldwide scale, the same research has not been performed at a more regional level at this present time. In terms of reporting many improvements could be made in order to produce more accurate results. Three main problems from reporting cases arose during the collection of data for this report. The problems included inconsistent reporting periods, lack of reporting and double counting errors. Firstly, inconsistent reporting periods made analyzing and comparing data a difficult task. In order to deal with this problem, data had to be streamlined into week-long periods. This led to possible inaccuracies, as a week could contain a mixture of data from the beginning and end of the week. Secondly, the lack of data available in some states and provinces did not allow for analysis at all. This could amount to a serious problem if a major area of infection is not identified. In order to correct this error, government policy changes mandating reporting would be essential. Finally, many geographic regions stopped recording case counts as a fear of double counting in a population that is always on the move. This was a major issue with the aboriginal population in Northern Canada. If a computer-based system was in place regionally, provincially and nationally to record patient data, then double counting would be eradicated. However, this modification would be costly to all levels of government and may not be feasible at the present time. Nevertheless, to progress in the field of monitoring and preventing infectious diseases, advanced computer reporting is a necessary step.

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