Multi Agent Simulation System for Rapidly Developing Infectious Disease Models in Developing Countries

Dean Yergens[1], Julie Hiner[2], Jörg Denzinger [3], Tom Noseworthy[1]

[1] Centre for Health and Policy Studies, University of Calgary,
Calgary, Alberta, Canada
{dyergens, tnosewor}@ucalgary.ca
[2] University of Calgary,
Calgary, Alberta, Canada
hiner@gusers.org
[3] Department of Computer Science, University of Calgary
Calgary, Alberta, Canada
denzinge@cpsc.ucalgary.ca

Abstract. The potential for the Avian Flu (H5N1) virus to become a pandemic disease has mandated an examination of public health surveillance, response and containment strategies for developing countries. We have developed a Multi Agent System Simulation system known as IDESS (Infectious Disease Epidemic Simulation System) that rapidly constructs infectious disease models from existing data for any geographical region. This approach addresses an important area of infectious disease outbreak management, as it allows public health professionals to rapidly construct a simulation model for any geographic region and observe how an infectious disease spreads between communities. Such simulations will facilitate testing of containment strategies for rapid response.

1 Introduction

The threat of the Avian Flu (H5N1) virus has highlighted the need for public health surveillance and infectious disease management [4]. The spread and impact of the H5N1 is a primary concern because of the virus' high mortality rate [7], which is anticipated to be similar to the flu pandemic of 1918 [6]. Moreover, with increased world travel and the ability to be in any region of the world within hours [5], spread of an infectious virus like H5N1 is expected to be rapid and incorporate wide geographical regions. For this reason, effective public health surveillance and management in developed countries must be on a global scale. It must take into account the lack of public health infrastructure in many developing countries.

We envisioned a system that is capable of constructing a simulation model that can be used for investigating the spread of disease from community to community, and that has the ability to test containment strategies. The system must be able to construct models for any geographic region and have the ability to alter "set" parameters such as transmission, incubation and mortality rate of the disease. The resulting simulation models must also mimic the traditional movement and interaction of people in the community. Finally, the system must be able to construct a model within hours in order to effectively "respond" once a situation has been identified.

To address the problem and requirements mentioned above we have developed a Multi Agent Simulation system known as IDESS (Infectious Disease Epidemic Simulation System) [2]. IDESS can rapidly construct simulation models of infectious diseases from existing data for any geographical region. We anticipate that our approach can be expanded from strictly handling infectious disease outbreaks to other environmental and humanitarian crises.

2 Infectious Disease Problem Definition

The concept of IDESS was not originally developed to address the pandemic flu concerns of the H5N1 virus. Instead, we had been seeing a lot of concern around bioterrorism and what the potential effects of a small pox virus release would be on a city in a developed country such as Portland, OR [3]. On the basis of a literature review, we concluded that many research efforts were concentrating on how an infectious disease would spread in a country such as the United States or England. We could find very little research, however, on the potential impact of a similar bioterrorist attack in a developing country.

We also concluded from examining many factors that affect developing countries (including poor public health surveillance, health systems under stress and the nature of infectious disease occurring in climates commonly found in developing countries) that an investigation was required to understand the type of system that was needed in this environment. The system we sought to create would manage and respond to an emerging infectious disease.

As explained previously, we identified several key elements that we deemed essential for our infectious disease simulation system to address. They were as follows:

1. Simulation model to be created in a manner of hours.
2. Ability to create a model for any geographic location in the world.
3. Use existing data to generate the simulation model.

4. Ability to visualize the results in a variety of ways.
5. From a software engineering perspective, the ability to quickly modify the agent's behaviors and interactions with other agents.

It was also identified that the same methodology used for the creation of the IDESS Multi Agent Simulation models could be expanded from infectious disease outbreaks to other scenarios such as environmental and humanitarian type crises that dealt with population movement and response strategies.

3. Multi Agent Simulation System

At the core of the multi agent based simulation is the Person Agent (PA). The PA acts just like a regular person does. The PA interacts with other PA's in the simulation model and also with the environment itself in terms of the Town Agent (TA).

Both the PA and TA have parameters and interactions that are associated with each agent. In the case of the PA, this may include knowing the age, sex, HIV status and infectious disease status of the person agent, as well as knowing how the PA interacts with other PA's when the PA infectious disease status changes.

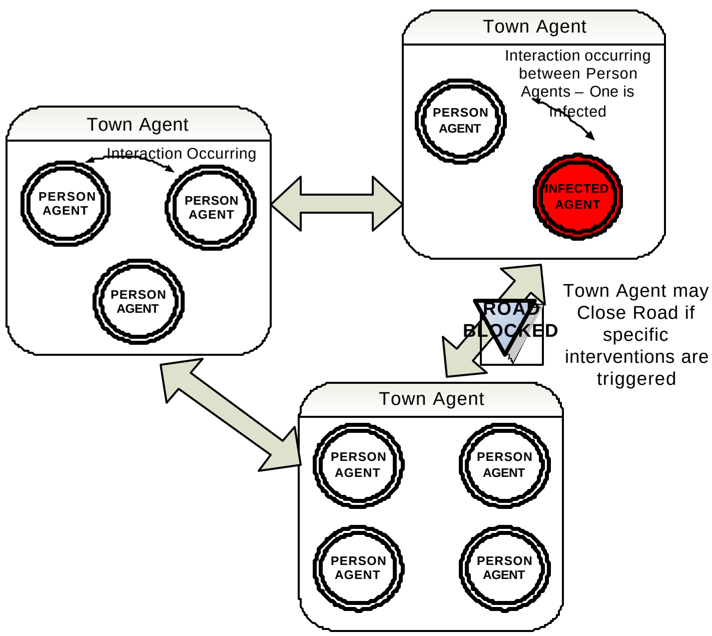

Fig. 1. Illustrates how the Town (TA) and Person (PA) Agents interact with each other in the Simulation environment.

In terms of the TA, parameters that the TA is aware of include the population of the town, as well as knowing which other TA's this TA has connectivity with. The interaction between TA's can also change based upon whether a containment strategy has been invoked, thus isolating the TA.

The agents and simulation environment is explained in more detail as follows.

3.1 Simulation Environment Development

The simulation environment is defined through a database that contains all the information that is required to create the multi agent simulation system including all the information about the Person and Town agents. This simulation environment is created through a series of steps. The first step is the generation of the environment, which is accomplished through extracting town and road information from standard GIS data. In this case, we use any ESRI E00 data set. An external program is used to import and parse the ESRI E00 data, defining a network graph. This node and edge representation is the equivalent of a town and road network and defines the only way a person agent (PA) can move from one town (TA) to another town (TA). Terrain is not factored into this model.

3.2 Person Agent Implementation

Each town has a pre-defined population that is stored as a parameter in the database that defines the model. From this population, agents are generated to accurately represent the population in the town. These agents are defined as the Person Agent (PA). Sex and age are assigned to each PA upon generation. The sex and age are based upon distributions that are stored in the parameter database or can be entered from a web-based application that is used to configure/verify the simulation models parameters.

In addition to the age and sex, the PA can have other demographic or clinical attributes assigned to it. An example of this, represented in the IDESS model, is HIV status. This attribute was originally defined as a key attribute for simulation of infectious disease outbreaks in developing countries due to the high HIV prevalence in many sub Saharan African countries and its associated impact on other infectious diseases.

A prime example of this was the original goal of this simulation model: to address the question of what would be the impact if the small pox virus was released in a country in sub-Saharan Africa where the HIV prevalence rate was high. The reason why this question is important and why it differs from models developed to look at the impact of a small pox outbreak in a city in North America or Europe is because the small pox vaccine has a negative impact on people who are HIV positive.

This would significantly affect the model because first responders to an infectious outbreak, such as the military and health care personnel, in highly infected HIV regions also have a high HIV infection rates. Which means vaccinating these individuals with the small pox vaccine is highly unlikely due to the increase chances of mortality resulting from the vaccination.

The PA operates in the town environment in the same manner as a regular person does. They interact with other PA's and may become exposed to the newly emerging infectious disease if one of the other PA's is infected and contagious. Once a PA becomes infected and symptoms start to develop, then their interaction with other PA's in the model changes. The logic for this is that once a person (PA) realizes they are sick then they will most likely change their pattern of behavior from a healthy individual to an individual with an illness.

The infectious disease can affect each PA during a number of stages. The first of these stages is the exposure and infection rate, which is a distribution of what is the likelihood that the PA will become infected when in contact with a PA in the contagious stage. The second stage is the incubation period, which is the number of days the PA is infected, although not yet showing symptoms. The third stage is the symptom period, which is the number of days until a PA shows symptoms and realizes that they are infected. The final stage is the illness period, which is the number of days a PA is infected and the likelihood of that PA eventually dieing from the illness.

Other factors that need to be addressed in person agents around the infectious disease component is whether the disease is a life long illness such as HIV, where they can continue to infect others, whether it is a one-time infection and the PA builds protective immunity towards the disease, or whether the infection is continuous where the PA can contract the disease and recover, but may contract the infection again, such as in the case of Cholera.

3.3 Town Agent Implementation

Each town in the simulation model is created as an agent. We call it the Town Agent (TA). The TAs are automatically generated from the configuration database and put into the simulation model environment. The TA parameters come from the database, where the Geographical Information System (GIS) data can be used to define the TA, define the population for that TA and also identify which other TAs are connected to the TA through the road network.

A TA is also defined as the epicenter of the infectious disease outbreak. That is to say, the first cases of the infectious disease are identified at the start of the simulation run.

The TA also has the ability to respond to various containment strategies that are triggered based upon certain parameters concerning the spread of the infectious disease. An example of containment is that once a TA reaches a specific percentage of infected PAs in the TA then a containment strategy is automatically invoked. This allows various scenarios to be tested, such as when should a containment strategy be applied.

3.4 Observing the Simulation

The Multi Agent Simulation implementation works on a per-day time-slice. On a daily basis all of the statistics for each town are transferred to a database that keeps track of the various simulation runs and all associated collected statistics. The database uses some web-based reporting forms that can query the data and display the trends of the simulation as well as the ability to see the information in geospatial format.

The method that we use to view the geospatial data is by using the Google Map API. The Google Map API is actually used in two stages of the IDESS system development. The first stage is to verify that the raw GIS data imports in the ESRI E00 format is actually preformed correctly and is able to display the mapping information accurately. The second stage is in the use of visualizing the geospatial data at any point in the simulation, or the results at the end of simulation. Since this is a system based upon infectious diseases, we thought it was prudent to be able to observe the data at specific time intervals rather then just at the end of the simulation run.

4. Experimental Evaluation

The following illustrates the simulation results from the multi agent simulation model. The model that was created, involved a dataset from Malawi, Africa and looked at how an emerging infectious disease originating in the city of Mzuzu would spread over a twenty-five day time period.

In total there were over 200 town agents created and over 10,000 person agents created in our initial tests to see if such a model could be built. Future work is to increase the size of the overall model, especially the person agents.

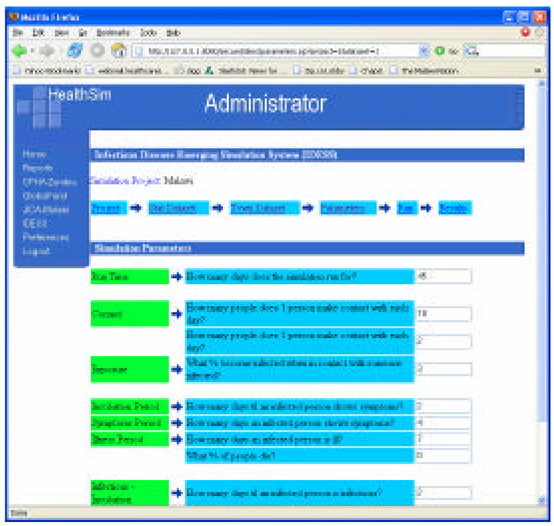

Fig. 2. Shows the infectious disease configuration parameters such as incubation rate, symptoms period, mortality rate, etc. These parameters are then used in the person agent to determine how the infectious disease spreads from one person agent to another person agent.

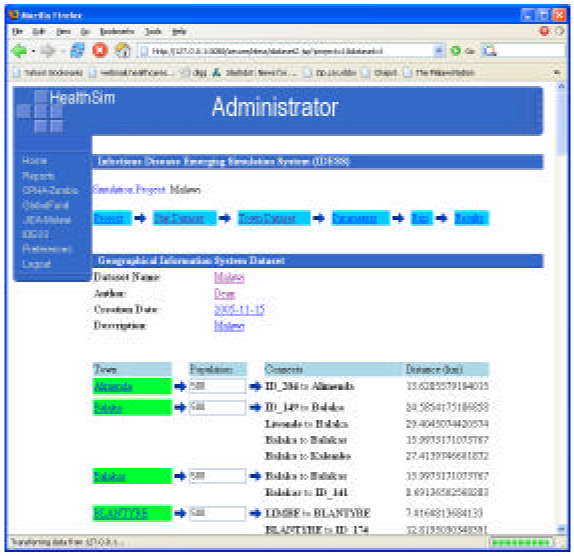

Fig. 3. Shows the Town agent configuration where the population can be redefined. It also shows which towns are connected to each other through the road network. The Population is stored in the database and can be manually edited.

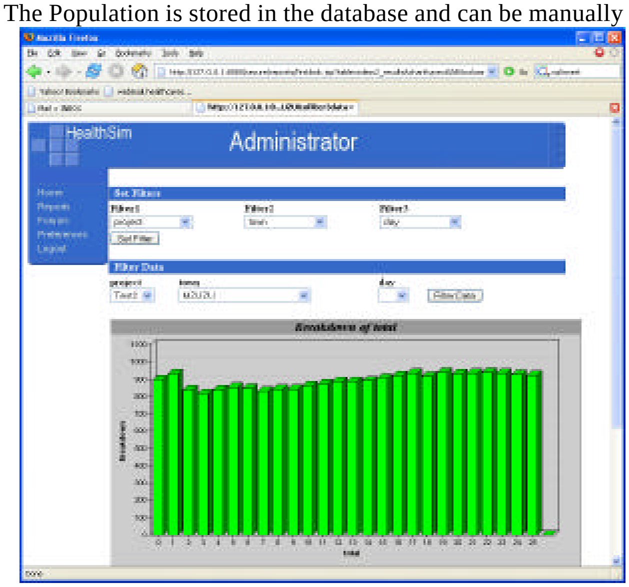

Fig. 4. Shows the reporting environment. In this case, shows the population census for one specific town on a daily basis from the simulation run results.

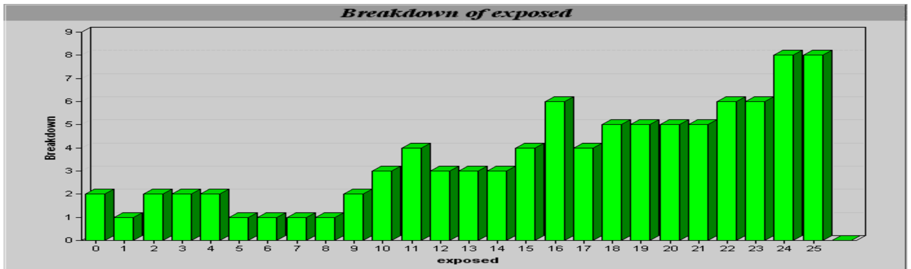

Fig. 5. Shows the number of people exposed on a daily basis to the emerging infectious disease.

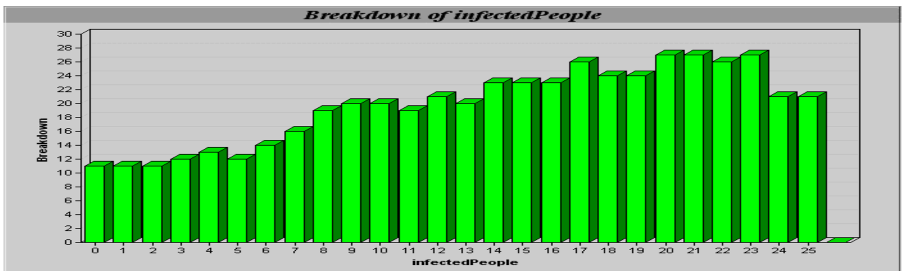

Fig. 6. Shows the number of people infected on a daily basis to the emerging infectious disease.

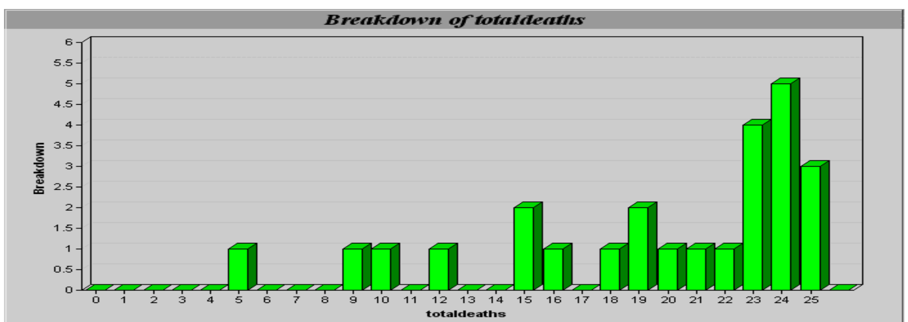

Fig. 7. Shows the number of people who died on a daily basis due to the emerging infectious disease.

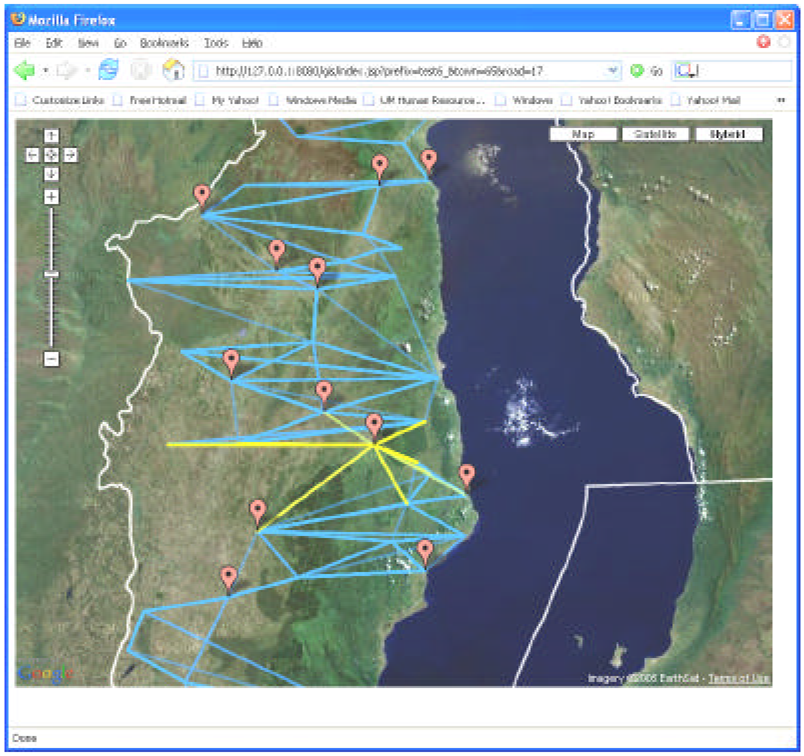

Fig. 8. Shows a geographical layout of the region being investigated through the multi agent based simulation model. The highlighted road network illustrates the "first contact" connections with the epicenter of the emerging infectious disease outbreak.

5. Conclusion

We have demonstrated an approach for constructing agent-based simulation models from existing geographical information systems data. Our approach is flexible in its ability to model any geographical location for an emerging infectious disease outbreak. This flexibility addresses the unpredictable nature of the geo-spatial location of where an infectious disease outbreak will occur. The IDESS has shown its ability to rapidly construct an agent based simulation model that can be used in the investigation of the spread of diseases in a given geographical environment.

We acknowledge that the simulation models generated by IDESS are not as sophisticated as other models. However, IDESS is envisioned to be a rapid "first look" approach to simulation when an acute infectious disease crisis occurs. IDESS can scale in sophistication as new agents and information are added to the model, which is similar in practice to the way that real-world management of infectious diseases occurs.

Multi agent system based simulation has proven to be an efficient approach to constructing simulation models in terms of software development. We have been able to add and modify agents with minimal effort and with no foreseeable impact on the integrity of the simulation model.

6. Future Work

There are three main areas of research that we would like to explore in terms of expanding IDESS. These three areas are as follows:

6.1 Expansion of Problem Definition

IDESS was originally created to construct infectious disease models to investigate how an outbreak occurring in one community would spread to another community.

From this first problem definition of investigating infectious disease outbreaks, we believe that IDESS can be expanded to look at other crises, such as humanitarian and environmental disasters. In terms of environmental disasters, examples include hurricanes, earthquakes and tsunamis. Additionally, we envision a role for IDESS in humanitarian response management. For example, where real-time simulation could have been used to aid in the relief transportation efforts after Hurricane Katrina was when a significant number of people from New Orleans were moved to the Houston Astrodome. The simulation model could have quickly estimated how many buses were required for the transportation. IDESS could also have estimated the arrival rate and the percentage of people requiring medical care.

6.2 Integration with GuSERS

In January 2000 we initiated another project dealing with the problem of public health surveillance in developing countries. This system deals with the problem and issues surrounding communication of infectious disease outbreaks in rural areas.

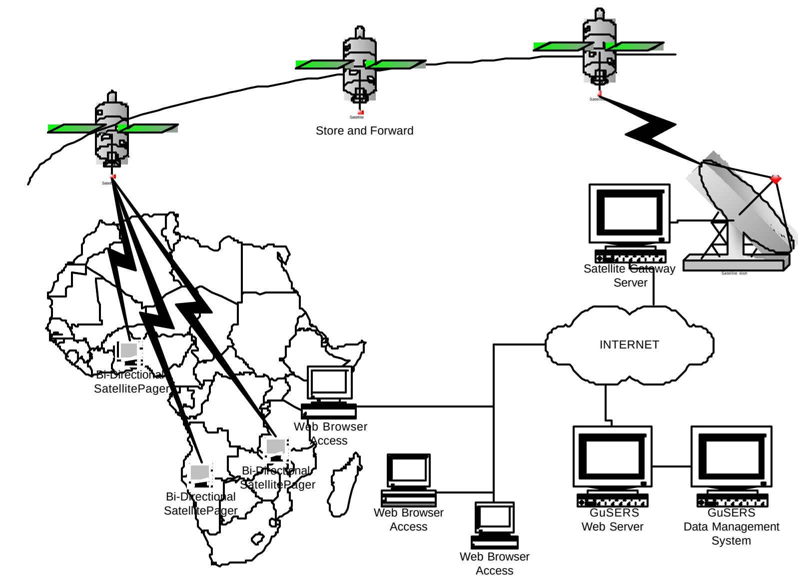

Fig. 9. Network topology of the GuSERS System.

This system is known as GuSERS (Global Surveillance and Emergency Response System) [1]. The GuSERS communication system was developed using a low-cost satellite based infrastructure that was independent of the ground-base telecommunications and electrical infrastructure. This was due to the fact that during times of emergency, the ground-based infrastructure is usually unavailable or unreliable. GuSERS uses low-bandwidth satellite two-way pagers combined solar-power tickle chargers to communicate with a web-based geographical information system.

The integration of the GuSERS and IDESS system is an important next step. It would allow a real-time communication system to be tightly integrated with simulation capabilities in which various disaster management or infectious disease response strategies. Such a system could simulate with increasing sophistication as information is updated through the GuSERS system.

6.3 Integration with other Data Sources

There is other readily available data that could be used by IDESS. We plan to include real-time weather data. This data could feed into the agent-based simulation model directly. Another source of data that we would like to include in our model is commercial airline traffic patterns. This would be valuable, as it would address the means by which the global spread of disease can occur through airline transportation.

7. Acknowledgements

Our thanks to the Centre for Health and Policy Studies University of Calgary and the following significant contributors John Ray, Douglas Hamilton, Deirdre Hennessy and Chip Doig. And we would like to acknowledge the Simkit Simulation Kernel developed by the TeleSim Group, Department of Computer Science, University of Calgary.

8. References

[1] Yergens, D.W., et al. Application of Low-Bandwidth Satellite Technology for Public Health Surveillance in Developing Countries. *International Conference on Emerging Infectious Diseases 2004*, (Feb. 2004), 63.

[2] Yergens, D.W., et al. Epidemic and Humanitarian Crisis Simulation System. *12th Canadian Conference on International Health* (Nov. 2005) Poster.

[3] Barrett, C, Eubank, S, Smith, J. If Smallpox Strikes Portland. *Scientific American*, (March 2005), 54-61.

[4] Ferguson, N, et al. Strategies for containing an emerging influenza pandemic in Southeast Asia. *Nature*, 437, 8 (September 2005), 209-214.

[5] Olsen, S J, et al. Transmission of the Severe Acute Respiratory Syndrome on Aircraft. *N ENGL J MED* 349:25 (Dec. 18, 2003) 2416-2422

[6] Johnson, N., Mueller, J. Updating the Accounts: Global Mortality of the 1918-1920 "Spanish" Influenza Pandemic. *Bull Hist. Med.*, 2002, 76:105-115

[7] De Jong, M., Tinh Hien, T. Review - Avian influenza A (H5N1). *Journal of Clinical Virology* 35 (2006) 2-13.