The Puerto Rico Emergency Preparedness Model

Gary B. Hirsch
Consultant, Creator of
Learning Environments
Wayland, Ma.
GBHirsch@comcast.net

Heriberto Centeno Marin
Departamento de Administración de
Servicios de Salud
Escuela Graduada de Salud Publica
University of Puerto Rico, San Juan, PR
Heriberto.marin@upr.edu

Abstract

The Puerto Rico Emergency Preparedness Model simulates the impacts of major events such as hurricanes on the demand for health care and capacity of the health care system. The model enables its users to simulate events with different characteristics and try out different forms of mitigation for reducing the health care consequences of those events. Development of the model began with an earlier model. That model was expanded by representing the populations and health care delivery resources of Puerto Rico's seven geographic regions. Other data on Puerto Rico's population, its health status, and health care were also inserted into the model. Particular attention was paid to simulating hurricanes and influenza pandemics. The project culminated with a training session and production of a Users' Manual to support the model's ongoing use.

The Puerto Rico Emergency Preparedness Model

Abstract

The Puerto Rico Emergency Preparedness Model simulates the impacts of major events such as hurricanes on the demand for health care and capacity of the health care system. The model enables its users to simulate events with different characteristics and try out different forms of mitigation for reducing the health care consequences of those events. Development of the model began with an earlier model. That model was expanded by representing the populations and health care delivery resources of Puerto Rico's seven geographic regions. Other data on Puerto Rico's population, its health status, and health care were also inserted into the model. Particular attention was paid to simulating hurricanes and influenza pandemics. The project culminated with a training session and production of a Users' Manual to support the model's ongoing use.

Background

The Puerto Rico Department of Health's Office of Public Health Preparedness and Response (OPHPR) contracted in 2013 the University of Puerto Rico-Center for Public Health Preparedness (UPR-CPHP) to develop an emergency health planning model for Puerto Rico. The UPR-CPHP, founded in 2004 by the UPR Graduate School of Public Health (UPR-GSPH), began as a collaborative initiative with the Emory University CPHP located in the Rollins School of Public Health in Atlanta. The UPR-CPHP specializes in two major areas: 1) addressing the training needs of first responders, public health professionals and healthcare facility personnel with the purpose of enhancing their level of preparedness and capability to respond effectively to disasters, emergencies and bioterrorism; and, 2) conducting large-scale assessments on the level of preparedness and response capability of healthcare institutions in Puerto Rico.

In addition, the UPR-CPHP has successfully completed large-scale assessment projects on the following topics: the level of preparedness and response capability of institutions that serve the elderly, pre-school children and tourists in Puerto Rico; the level of emergency preparedness and response capability of organizations that provide services to adults with mental retardation in Puerto Rico; volunteer organizations and their role in emergency preparedness and response in Puerto Rico; the level of emergency preparedness and response capability of hospital emergency rooms in Puerto Rico; and, an assessment of the emergency preparedness and response capability of community organizations and healthcare facilities that provide services to persons experiencing homelessness in Puerto Rico. The UPR-CPHP also conducted a hazard vulnerability assessment (HVA) of Puerto Rico's public health, medical care services and mental health systems. This emergency health planning model for Puerto Rico will be integrated into the HVA.

Surveys have indicated a great need for emergency preparedness planning. The most significant findings from a hospital emergency rooms study show limitations in the availability of medical personnel required to respond to a mass casualty event in Puerto Rico. Less than half of the institutions indicated the possibility of providing continuity of services up to 96 hours after a catastrophic event. Only 25% have a written hospital emergency plan; 45% fail to review their plans annually. Only half have conducted a hazard and risk vulnerability analysis. Almost 25% of the facilities lack a morgue, and over half of these do not even have a written agreement with another facility to handle corpses. The average storage capacity for those with morgues is only three corpses, and they have no possibility to increase this capacity. The average number of body bags available is eight.

There is no uniformity of emergency codes and alerts. More than half of facilities report the absence of furniture anchors in the emergency room. Nearly half lack a redundant electricity supply system in the emergency room. In addition, findings reveal serious gaps in facility security given that security personnel can only work an average of 48 hours without requiring outside help. Regarding epidemiological surveillance, a quarter of the facilities experienced problems in this area due to limited staff. One third of health facilities' personnel receive little or no emergency preparedness and disaster training. With regard to training sources, the study showed that, contrary to what is recommended in the literature, more than half of the facilities use internal instructors to offer teaching on the management of mass casualty disasters.

It is also well documented that Puerto Rico is vulnerable to a great diversity of natural phenomena such as hurricanes, tsunamis, flooding and landslides due to its geographic position in a tropical and seismic active zone. Studies cited by the Puerto Rico Seismic Network (PRSN, 2015) state that a great part of the Island is at high risk of being affected by an earthquake or other seismic events such as tsunamis, liquefaction and/or landslides. As relatively recent events have demonstrated, the Island is also vulnerable to events created by human actions such as fires, spills of hazardous substances, among others. These realities clearly present a need to formulate public policy to efficiently and effectively address these challenges.

Resilience is essential for safeguarding communities and for building safer communities. Supporting disaster-resilient communities requires preparedness, mitigation, response and recovery (Prosser and Peters, 2010). Emergency and disaster preparedness offers greater security to the population, government entities and communities. Moreover, an essential component of building safer and resilience communities is to increase the level of preparedness and the response capability of the healthcare system. It is, therefore, timely and important that the UPR-CPHP is currently conducting comprehensive hazard and vulnerability assessment of the Island's public health, medical and mental/behavioral health systems.

To complement and enhance this hazard and vulnerability assessment, this study adapted and implemented a system dynamics model originally developed by Gary Hirsch, which will support emergency health care planning for Puerto Rico. The model is based on one originally developed by Hirsch in 2003-2004 for the Sandia National Labs under contract to the U.S. Department of Homeland Security (Hirsch, 2004). That model had been designed to be generic and broadly applicable to a range of geographic areas and types of incidents including hurricanes. A review of that model suggested that it could be applied to Puerto Rico with only small changes. The principal modification in adapting the earlier model for use in Puerto Rico was the disaggregation of the model into 7 regions using subscripting in Vensim. This was deemed important in order to be able to simulate different paths of hurricanes through the island and the effects they might have on regional populations and health care systems.

The Emergency Preparedness Model builds on extensive health care applications of System Dynamics. Relevant areas of application include:

- Simulation-Based Learning Environments for Population Health: Microworlds, HealthBound, and ReThink Health
- Chronic Illness: Diabetes, Cardiovascular Disease, Children's Oral Health
- Contagious Disease: Influenza, HIV-AIDS
- Health Care Delivery: ER and Hospital Management, Patient Waiting Lists, Organ Transplantation
- Emergency Preparedness:
  - Sandia National Labs for Dept. of Homeland Security
  - West Virginia Surge Capacity Modeling

Other emergency preparedness work at Sandia developed models of pandemic influenza and created a simulator that could be used to train local officials in responding to that health care emergency (LeClaire et al, 2009). The work in West Virginia developed a model for planning hospital surge capacity to accommodate a variety of emergency situations (Hoard et al, 2005).

The following sections of this report describe the structure of the model and sample simulations produced with it.

Model Structure

Figures 1-4 provide an overview of the model's structure. Figure 1 shows how an event such as a hurricane affects a population and creates health care demands as well as damaging the health care system's ability to respond through direct effects and impairment of the infrastructure. Patients have any of several outcomes after receiving health care including temporary or permanent disability as well as returning to normal functioning. Figure 2 presents a similar overview in a format specific to System Dynamics models. The boxes are called stocks and represent people or other quantities in a particular status at any point in time. The "pipes" between these stocks are called flows and represent the movement of people between those different statuses. Figure 3 breaks these flows into more detail as patients move among physicians' offices and clinics, emergency services, hospital emergency rooms, inpatient beds, and long-term care facilities. Figure 4 shows how direct damage effects, illness and injury of health care personnel, and infrastructure failures impair the capacities of various health care facilities to treat patients.

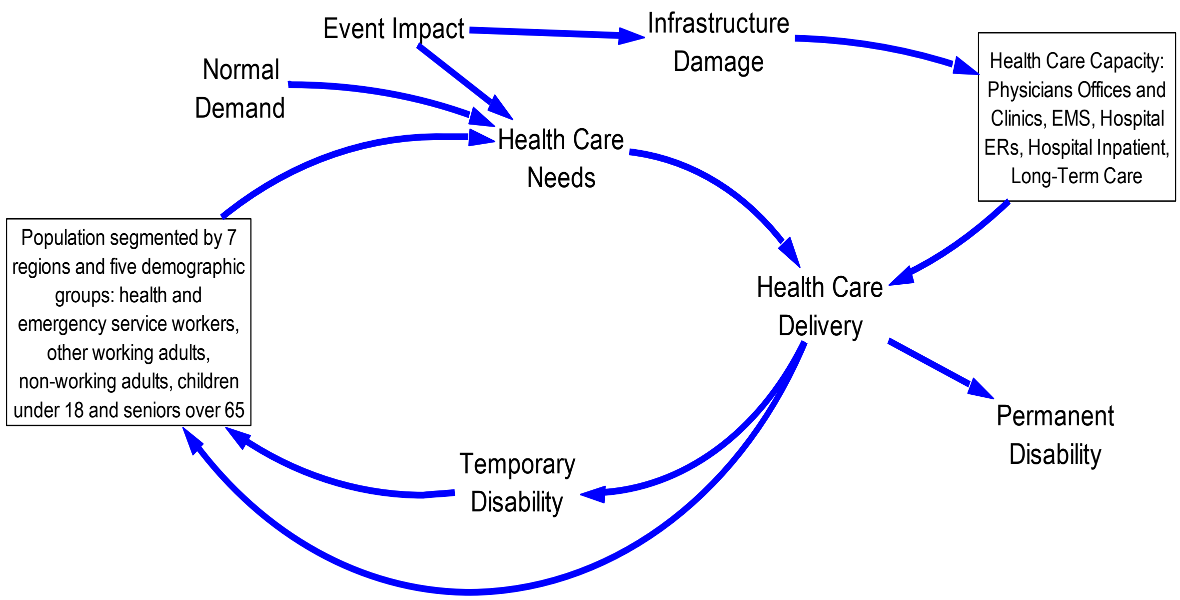

Figure 1: High-Level Model Overview

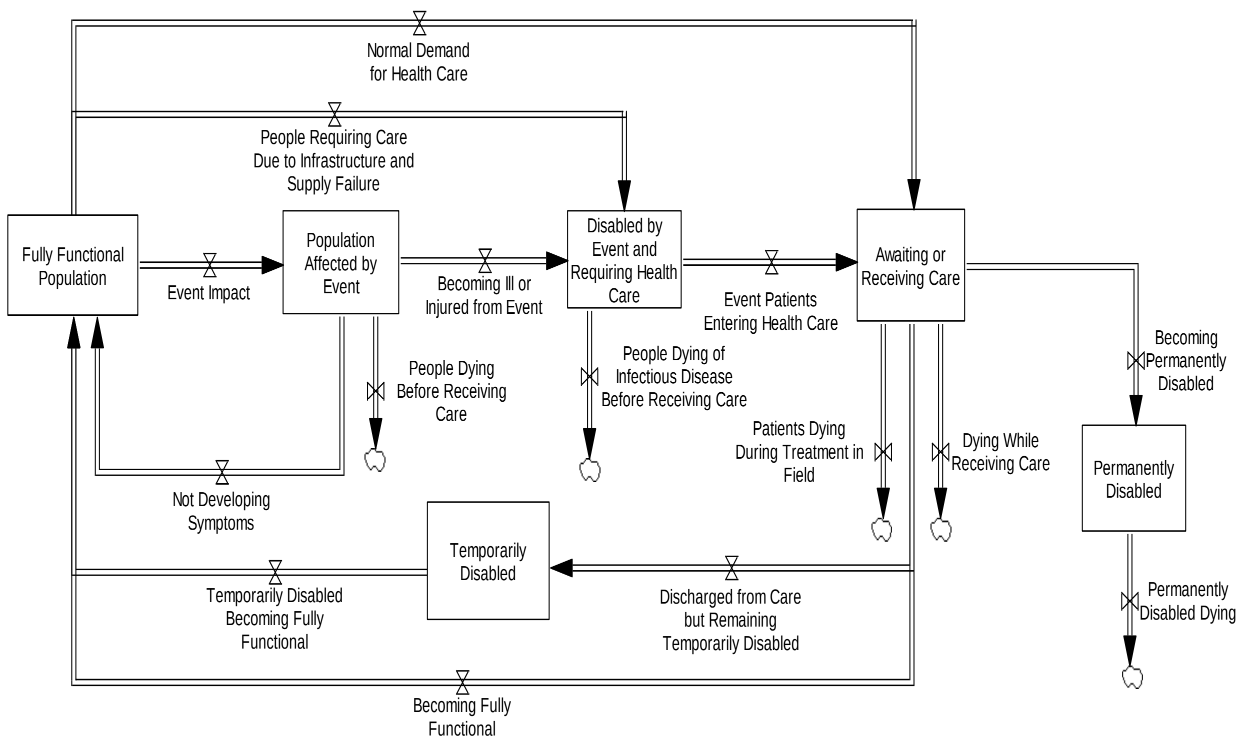

Figure 2: Overview of Patient Flows After an Event

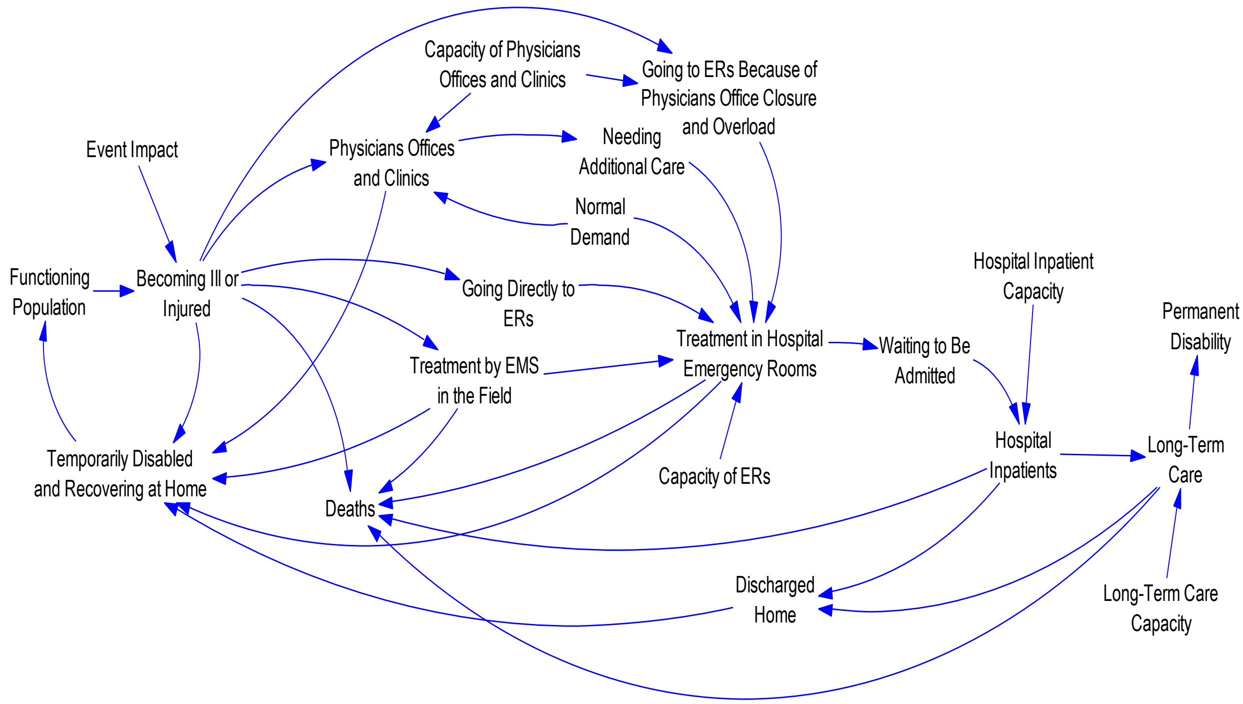

Figure 3: More Detailed Overview Showing Various Patient Health Care Pathways

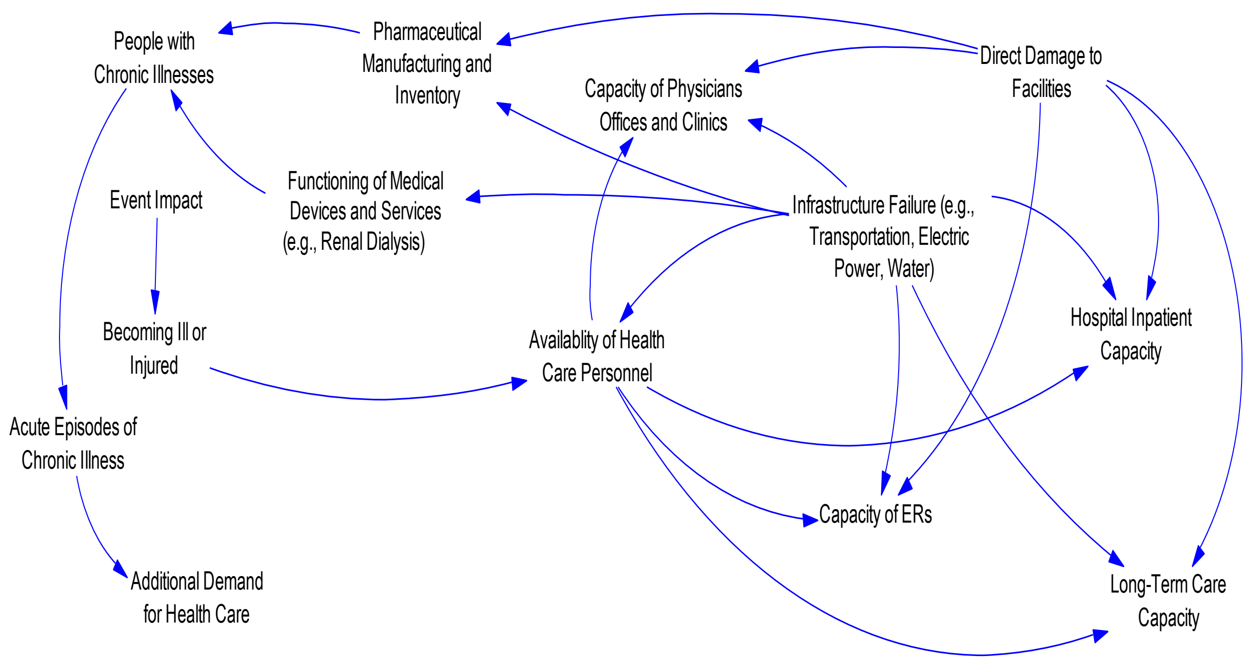

Figure 4: Impacts of Event on Health Care Capacity

As indicated in Figure 1, Puerto Rico's population is divided into its seven regions and into five population groups in each region:

- Health care and emergency services personnel
- Other working adults
- Non-working adults
- Children under 18
- Seniors over 65

All calculations of health impact and health care utilization are done for each of the 35 region-population group combinations.

Figures 5-7 show parts of the structure of the model in more detail. Figure 5 shows that there are three flows calculated for physicians' offices and clinics: normal utilization, patients developing symptoms of illness or injury as a result of the event, and patients receiving prophylaxis (vaccination)to prevent consequences of infectious disease. Patient of all three types await care until there is adequate capacity. These three flows share the capacity of the physicians' offices and clinics to provide care. That capacity can be impaired by direct damage, infrastructure failures such as widespread power outages, and health care personnel becoming sick or injured. Most patients return home after receiving care, but some must be referred to hospital emergency rooms for additional care. If physicians' offices and clinics have long waits for appointments, patients may bypass them and go directly to hospital ER's.

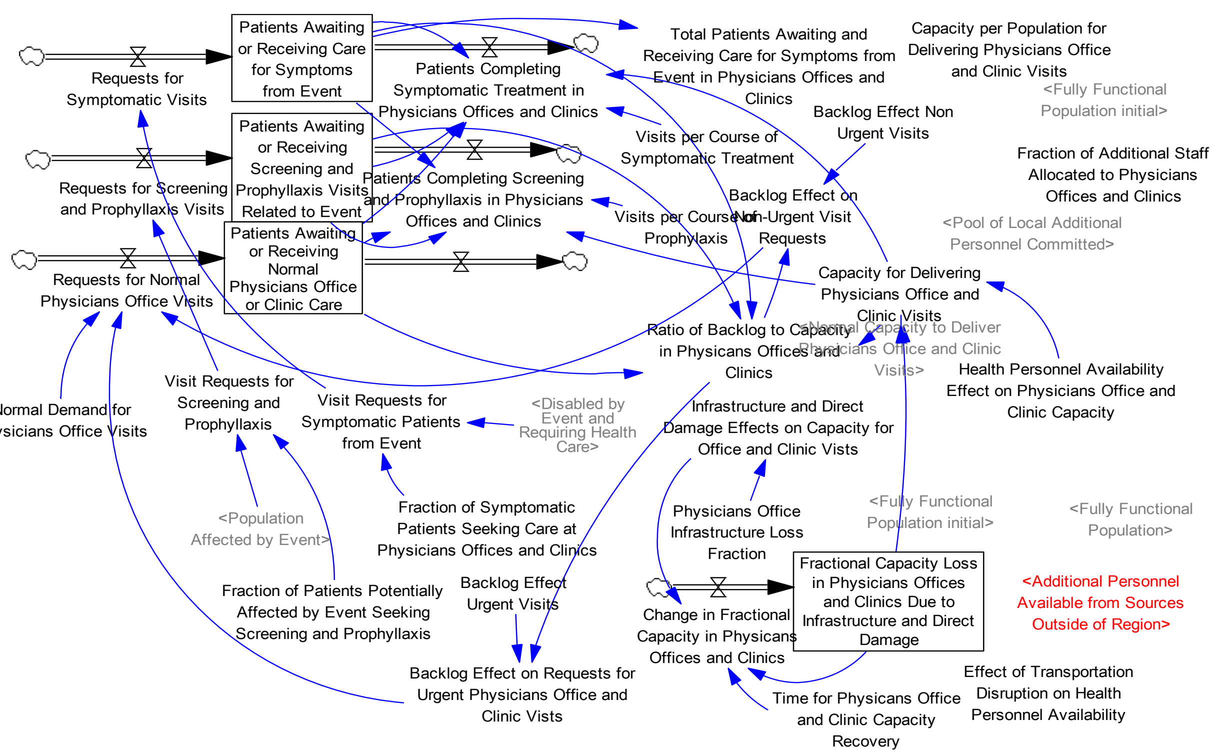

Figure 5: Patient Flow Through Physicians' Offices and Clinics

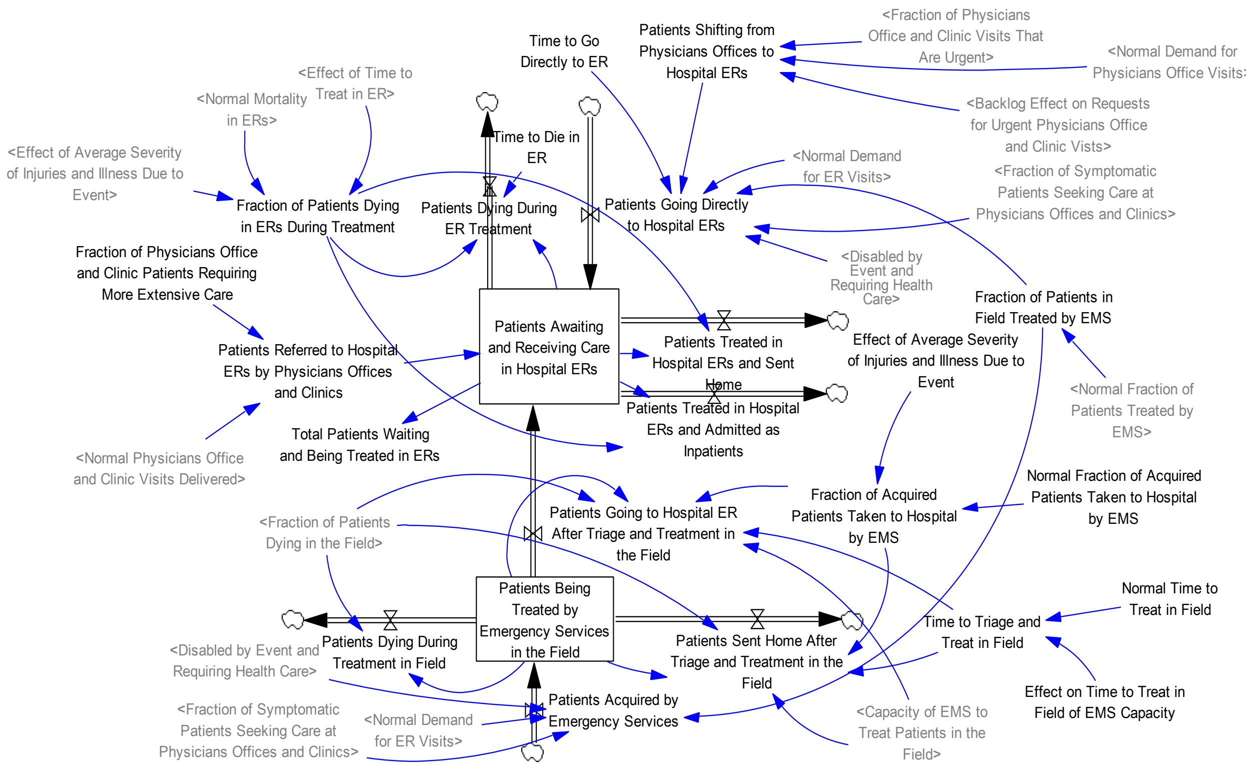

Figure 6: Patient Flows Through EMS and Hospital Emergency Rooms

Figure 6 shows how patients flow through the emergency medical services and hospital emergency rooms. Some patients are acquired and treated by EMS while others go directly to ER's by themselves. Patients treated by EMS can remain at home if they require no further care or be brought to a hospital ER for further treatment. Patients brought to the ER by EMS and those going directly to the ER themselves enter a queue and are seen as quickly as the ER's capacity allows. Once seen and treated in the ER, patients can be sent home or kept for admission to the hospital.

Figure 7 shows the structure related to hospital admissions. There are two flows of patients: those who come through the ER and have urgent needs and those with non-urgent problems requiring elective surgery or other treatment and who can be given lower priority if there is a major casualty event. Patients are admitted when beds become available and can be discharged home or to long-term care in a Skilled Nursing Facility. More severe injuries and illness and diminished capacity due to lower personnel availability can both result in patients staying in the hospital longer. Long delays in receiving care can result in larger fractions of patients dying while in treatment and fractions requiring long-term care after discharge. Hospitals' ER and inpatient capacity is subject to the same forces as physicians' offices and clinics, but may be less vulnerable to infrastructure disruption if they possess emergency generators and other backup equipment.

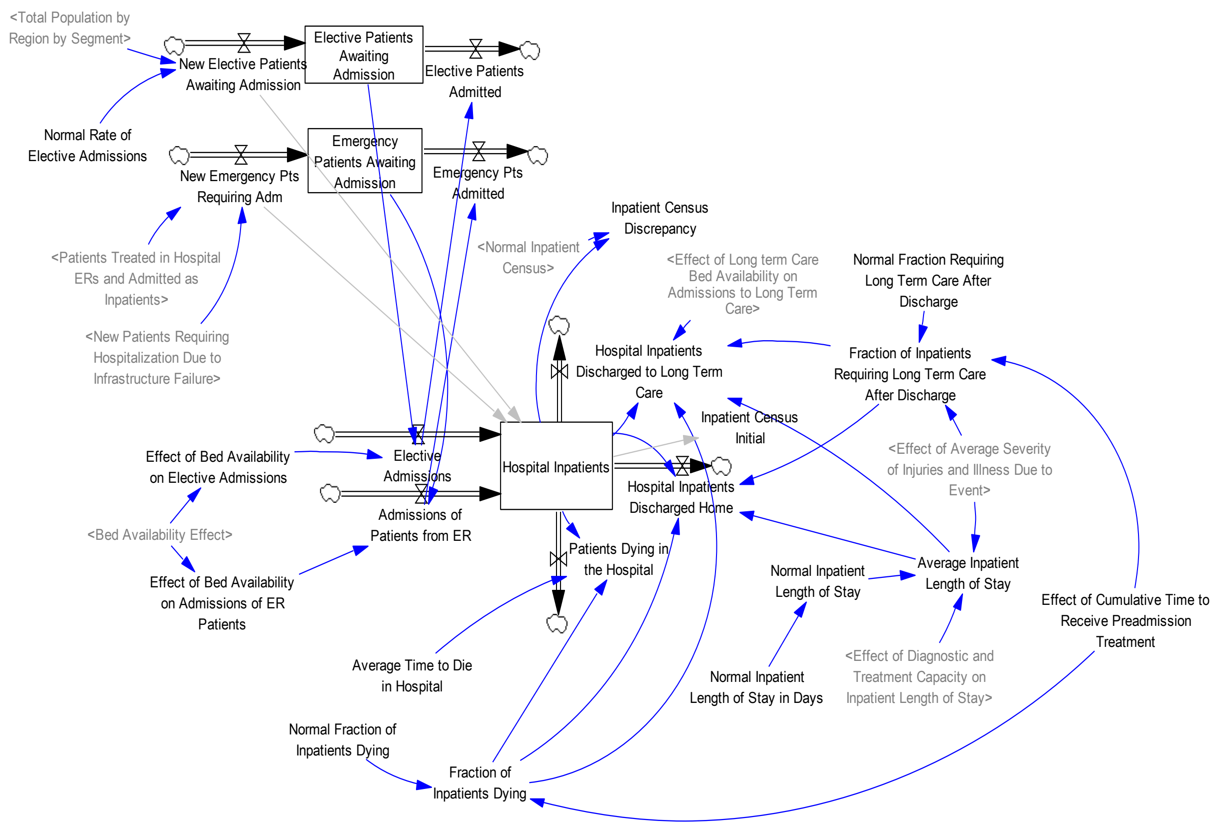

Figure 7: Hospital Inpatient Care

Other sectors of the model deal with the utilization and capacity of long-term care and the availability of pharmaceuticals and other health care supplies. The model keeps track of the chronically ill population and projects the number that will develop health problems depending on how low pharmaceutical and other supply inventories are likely to fall as a result of interruptions in local manufacturing and damage to the transportation infrastructure. The model also projects the numbers of people who might develop health problems as a result of loss of electrical power needed for assistive devices and to provide services such as renal dialysis. Finally, the model also contains various mitigation strategies to help regions deal with the effects of hurricanes such as:

- Mobilizing local personnel such as those in the Medical Reserve Corps
- Bringing in additional personnel from other regions less effected by the event
- Creating additional temporary ER and inpatient beds through Disaster Medical Assistance Teams (DMATs) and field hospitals
- Augmenting local pharmaceutical supplies with shipments from other regions

Model Validation: Simulating the Effects of a Hurricane

Hurricanes have multiple health impacts that the model should be able to capture:

- Initial injuries and deaths, extent depending on nature and path of the storm
- Injuries flowing into the health care system over a number of days as people are able to travel and become injured during recovery activities
- People dependent on medical devices and services requiring care as a result of power failures
- Additional demand shifting from physicians' offices and clinics that are closed due to damage or infrastructure failure
- A second wave of demand if there is prolonged infrastructure failure and people with chronic illness lack medication and supplies

We searched for data to validate that the model was producing results that fit a pattern similar to historical hurricanes. Unfortunately, there was very limited data in the literature that detailed health impacts beyond fatalities. However, there was one good article that detailed emergency room utilization and inpatient admissions in the aftermath of Hurricane Katrina in three coastal counties in Mississippi. **(**Surveillance for Illness and Injury After Hurricane Katrina --- Three Counties, Mississippi, September 5--October 11, 2005, CDC Morbidity and Mortality Weekly Reports (MMWR), K M McNeill et al, March 10, 2006 / 55(09);231-234) Highlights from that article included:

- During first week after storm, excess visits to ERs/DMATs equivalent to 2% of population
- During next four weeks, excess ER/DMAT utilization was equivalent to 1% of the population per week
- Much of the utilization was for routine problems in the aftermath of the storm and recovery (e.g., infected cuts, insect bites)
- 3.7% of ER visits required patients to be admitted, much lower than typical fraction (13% from NHAMCS), indicating that ERs/DMATs were handling many routine problems that would have gone to physicians' offices and clinics

Another article corroborated those results qualitatively for a series of hurricanes in Central Florida that produced similar patterns of demand. (THE IMPACT OF A SERIES OF HURRICANES ON THE VISITS TO TWO CENTRAL FLORIDA EMERGENCY DEPARTMENTS, E. Platz, H. Cooper, S. Silvestri, and C. Siebert, The Journal of Emergency Medicine, Vol. 33, No. 1, pp. 39–46, 2007)

The following set of simulations show how these components are added in layers to produce an overall effect that tracks the impact presented in the Hurricane Katrina article. The three simulations use only the Metro region for the sake of an example and apply the impacts of a hurricane in three steps:

1. Direct effect of a hurricane resulting in injury or illness for 3% of the population in the Metro region. (green line)
2. #1 plus additional effects of power failure resulting in:
   - Closure of half of physicians' offices and clinics, recovering gradually over one week

- A number of people who require power for medical devices and services (e.g., renal dialysis) needing medical care (red line)

3. #2 plus other widespread infrastructure failure resulting in
   - Loss of half the transportation network, recovering gradually over a week, making it difficult for staff to get to work and affecting health care capacity; also making it difficult to resupply pharmaceuticals and supplies
   - In addition, loss of half the region's pharmaceutical manufacturing capacity, recovering gradually over four weeks; reduced supply due to manufacturing and transportation problems causing people with chronic illnesses to experience acute episodes
   - Reduction in hospital capacity of 20% recovering gradually over one week (blue line)

Figures 8-10 graph the impact of the hurricane on the numbers of people waiting for care and being treated at physicians' offices and clinics, being treated and waiting for care in hospital emergency rooms, and being inpatients in hospitals. The horizontal axis is time over 1440 hours (60 days) and the vertical axes are the number of people in each status. The red and blue lines reflecting the last two simulations clearly show that the higher levels and second wave of demand in patients waiting and being treated at physicians' offices and clinics and hospital emergency rooms. The first peak in emergency room utilization (red line) reflects the higher demand as patients face a backup at physicians' offices and clinics and shift to the ER instead. This is consistent with the patterns demonstrated in the articles cited above. The first peak also

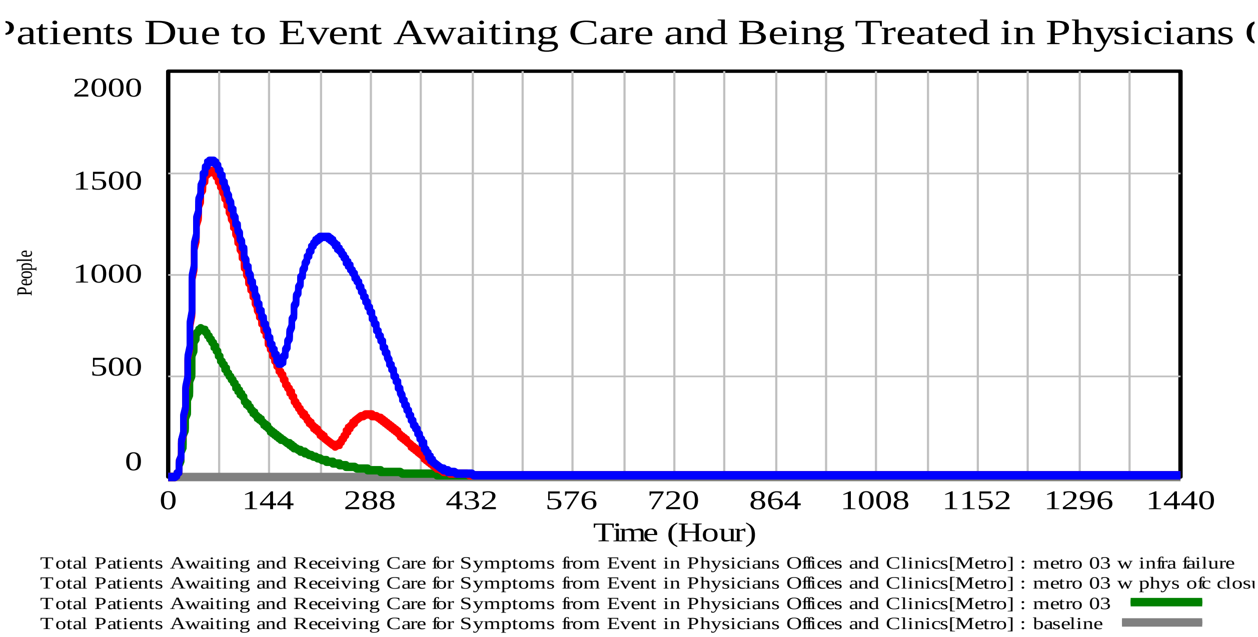

Figure 8: Patients Due to Event Awaiting Care and Being Treated in Physicians' Offices and Clinics Reflecting Immediate Effects of Hurricane, Physicians Office Closures, and Widespread Infrastructure Failure

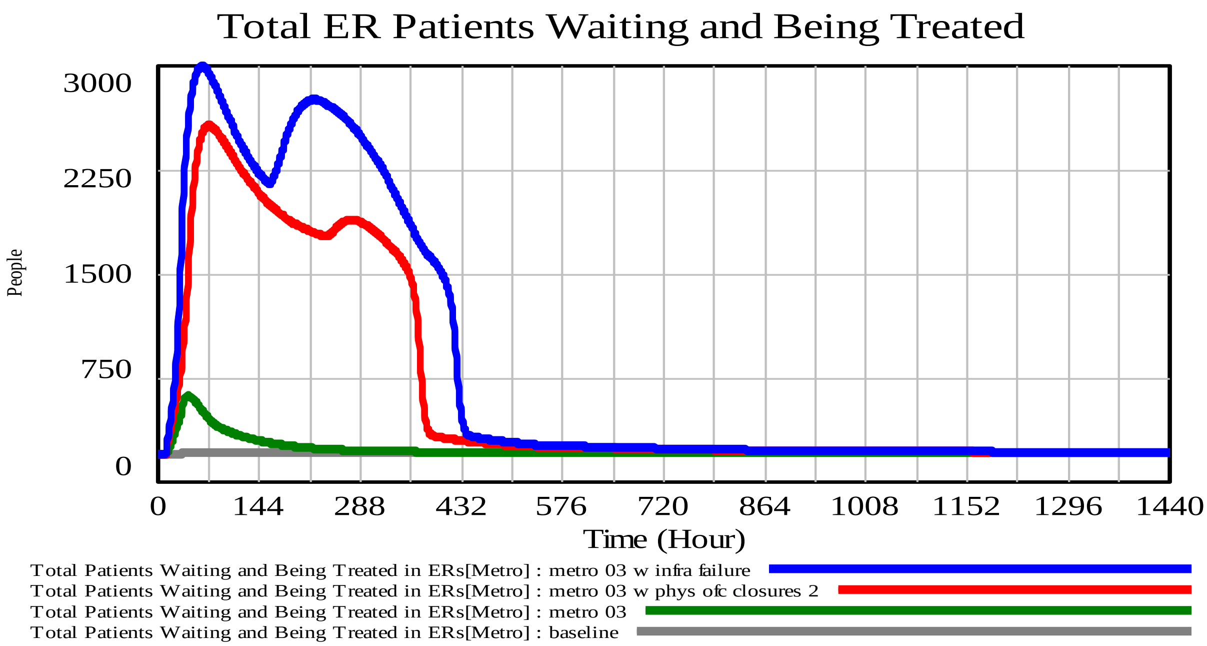

Figure 9: Patients Due to Event Awaiting Care and Being Treated in Hospital Emergency Rooms Reflecting Immediate Effects of Hurricane, Physicians Office Closures, and Widespread Infrastructure Failure

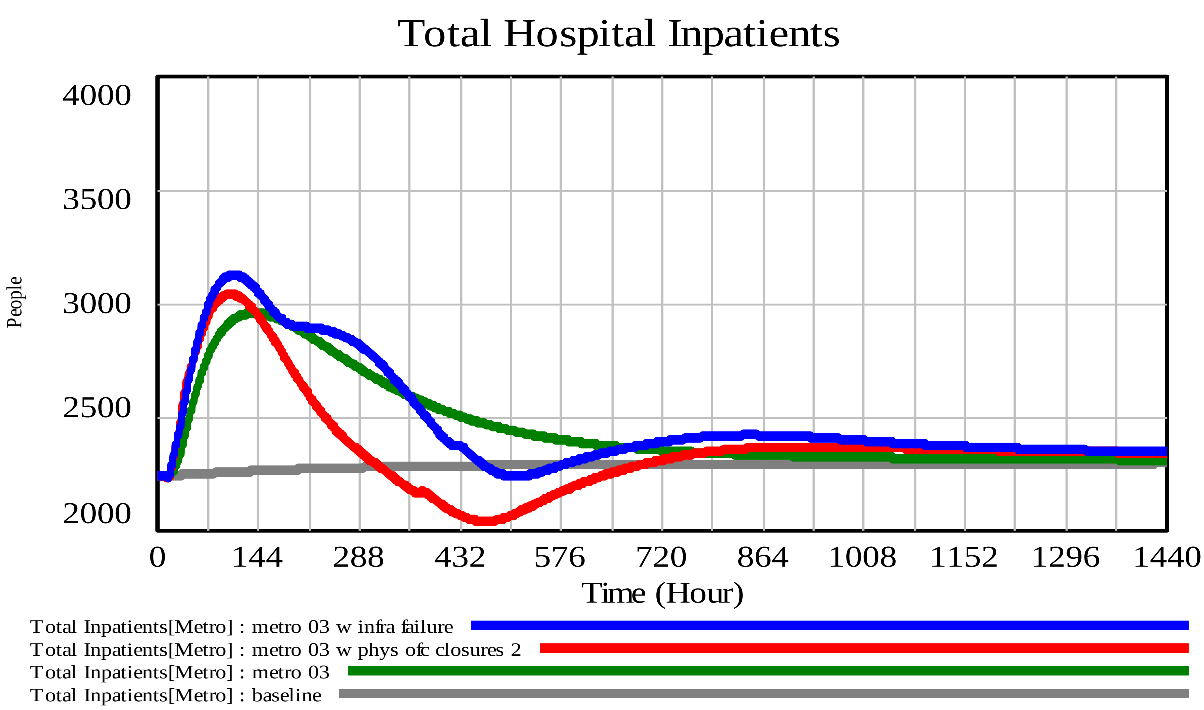

Figure 10: Hospital Inpatients Reflecting Immediate Effects of Hurricane, Physicians Office Closures, and Widespread Infrastructure Failure

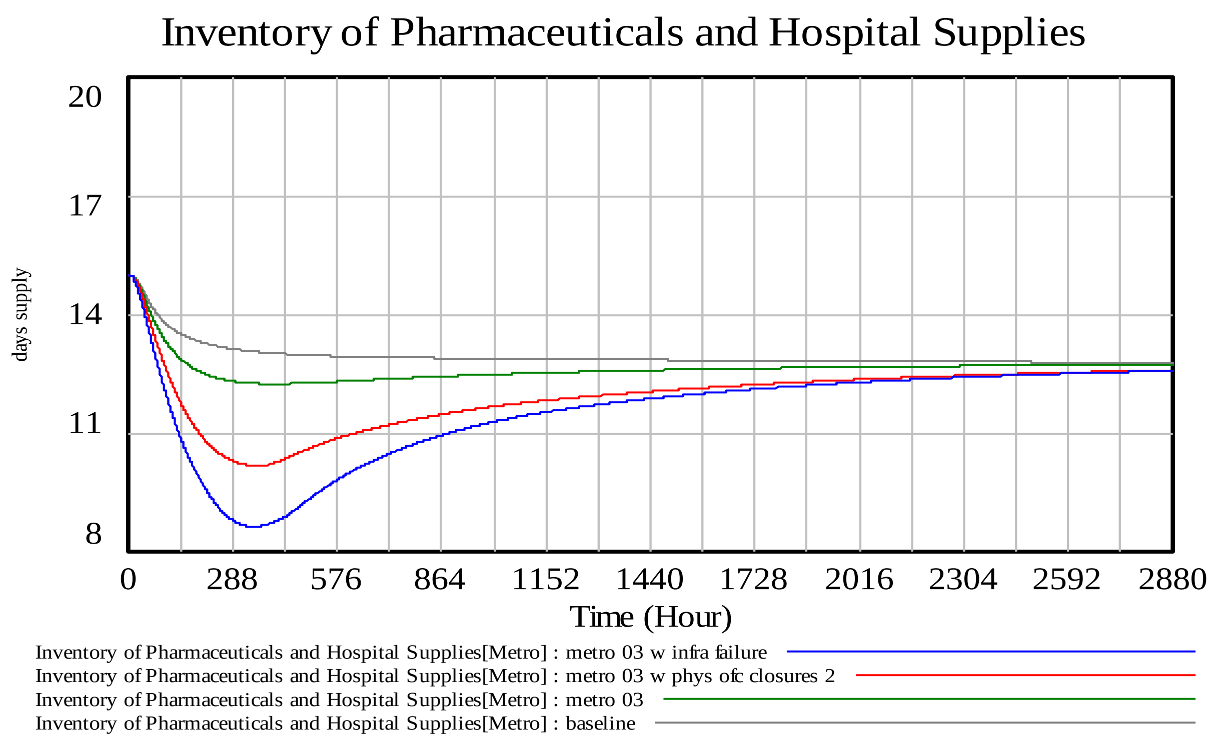

Figure 11: Pharmaceuticals and Supply Inventories

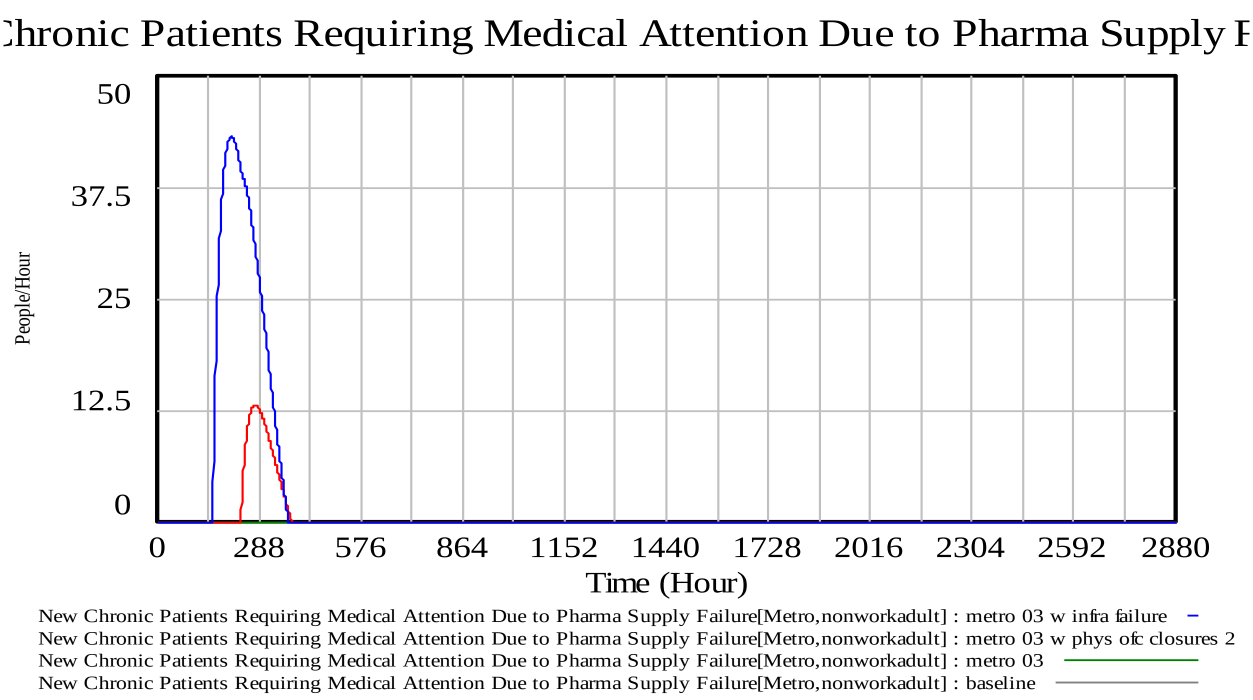

Figure 12: Chronic Patients Requiring Medical Attention

reflects the needs of people who depend on electricity and other types of infrastructure to power medical devices and require care if the infrastructure is damaged by a hurricane. The second peak (blue line) in both physicians' office and clinic and ER utilization reflects the effects of prolonged infrastructure failure, especially transportation, and damage to local pharmaceutical and health care supply manufacturing. People with chronic illnesses lacking their medications begin showing up as they develop health problems that require attention. Figures 11 and 12 show how dips in pharmaceutical inventories can lead to people needing medical attention.

This combination of factors included in the third simulation produce ER utilization patterns that closely match those described in the Hurricane Katrina article. Table 1 compares cumulative ER visits as a fraction of the population after the event between the baseline simulation with no hurricane and the third simulation. After one week, 2% more of the population has been to the ER and after five weeks, another 4% more in the ensuing four weeks or 1% per week have been to the ER, very close to the excess utilization experienced after Hurricane Katrina.

		After One Week		After Five Weeks
Hurricane		0.034		0.127
Baseline		0.013		0.067
Cumulative Fraction of Population Going to Hospital ERs				

Table 1: Comparison of ER Visits as a Fraction of Population Between Baseline and Hurricane

Simulating Hurricanes with Different Characteristics

Simulating a hurricane with different characteristics involves several steps:

1. Choose the affected regions. If you imagine a storm following a particular path across the island (perhaps based on historical storms), which of the 7 regions will be affected and with what relative severity? Alternatively, you can look at one region at a time.

2. Decide on the relative impacts on population groups within each of those regions. Population groups represented in the model are health and emergency services workers, other working adults, non-working adults, children, and seniors. Different groups might be assigned different impacts. Children, for example, might be assigned a lower expected impact if it is anticipated they will be evacuated in advance of a storm and not be involved in recovery activities where many of the injuries occur.

3. Set up the simulation using the parameters on the model's Hurricane Control Panel. You must set at least some values of the parameter Maximum Fraction of Population Affected to other than zero in order to have a health impact on the population. Values can be set for each region and population segment that will be affected. Set other

parameters to reflect other hurricane characteristics such as the Severity of Illness and Injury Due to Event. Also, set any parameters that reflect assumed extent of damage to the health care and other infrastructure and time it will take to recover from each type of damage.

4. Run the simulation to project the hurricane's impact. Look at the summary graphs to get a sense of the overall impact in this simulation compared to others that you have done. If you want to better understand what is happening, you can go to different sectors of the model and examine how the results play out for any of the model's variables. Once you have understood the results of the simulation, you will, no doubt, have additional "What if?" questions that will be the basis for more simulations. You will also want to experiment with the parameters on the right-hand side of the control panel that make additional resources available to see what effect they have in helping the affected regions cope with peaks in demand for health care and impacts of infrastructure failure. Continue to run simulations to better understand a hurricane's impacts on the health care system and how they might be mitigated.

Figure 13 shows the Hurricane Control Panel for selecting characteristics of the event and possible mitigation strategies to reduce the size of the peaks shown in Figures 8-10. The control panel also enables users to specify the degree of impairment of different parts of the health care system and infrastructure and the time over which they might expect to recover to being fully functional.

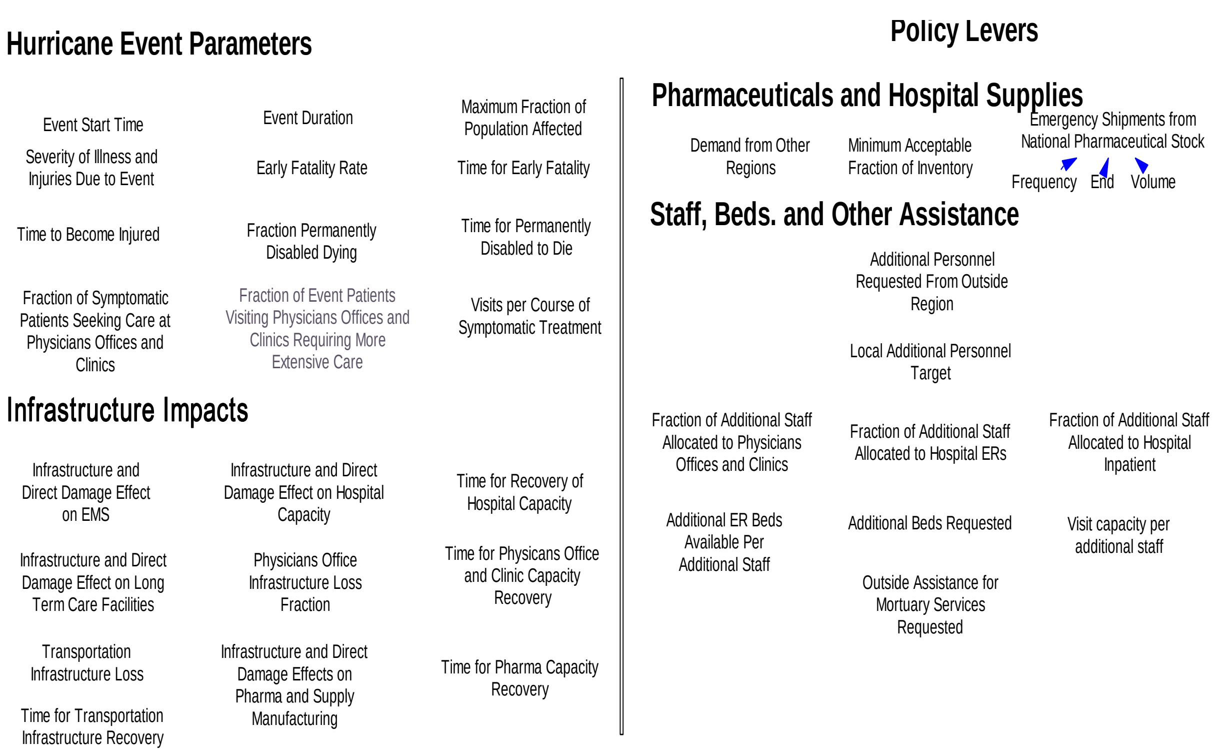

Figure 13: Hurricane Control Panel

As shown In Figure 13, mitigation strategies can include bringing in additional personnel from the Medical Reserve Corps and other groups and allocating them to different services, creating additional hospital beds with temporary field hospitals, establishing additional Emergency Rooms using tents and in public buildings, and drawing pharmaceuticals and other supplies from emergency stockpiles.

Simulating an Influenza Pandemic

The other type of event that was simulated was an influenza pandemic that affects a sizable fraction of the population. Figure 14 shows how infectious disease events are represented in the model. The left-hand side of Figure 14 shows the branching logic for how infectious disease events can be represented. The range of infectious disease events include contagious diseases such as influenza and diseases caused by pathogens introduced by natural circumstances or intentional acts. The right-hand side of Figure 14 shows the various factors that affect the rate of spread of the disease. One key parameter is the Contagion Multiplier for Bio-event that affects the rate and extent of spread of the disease.

Figures 15-17 show how a fairly serious influenza outbreak might spread through the population of the Metro region. Note the long time scale, 120 days, over which the outbreak develops, peaks, and declines. As shown in Figures 16 and 17, the sharp increase in patients arriving at hospital ER's results in a large backlog of patients awaiting admission to the hospital.

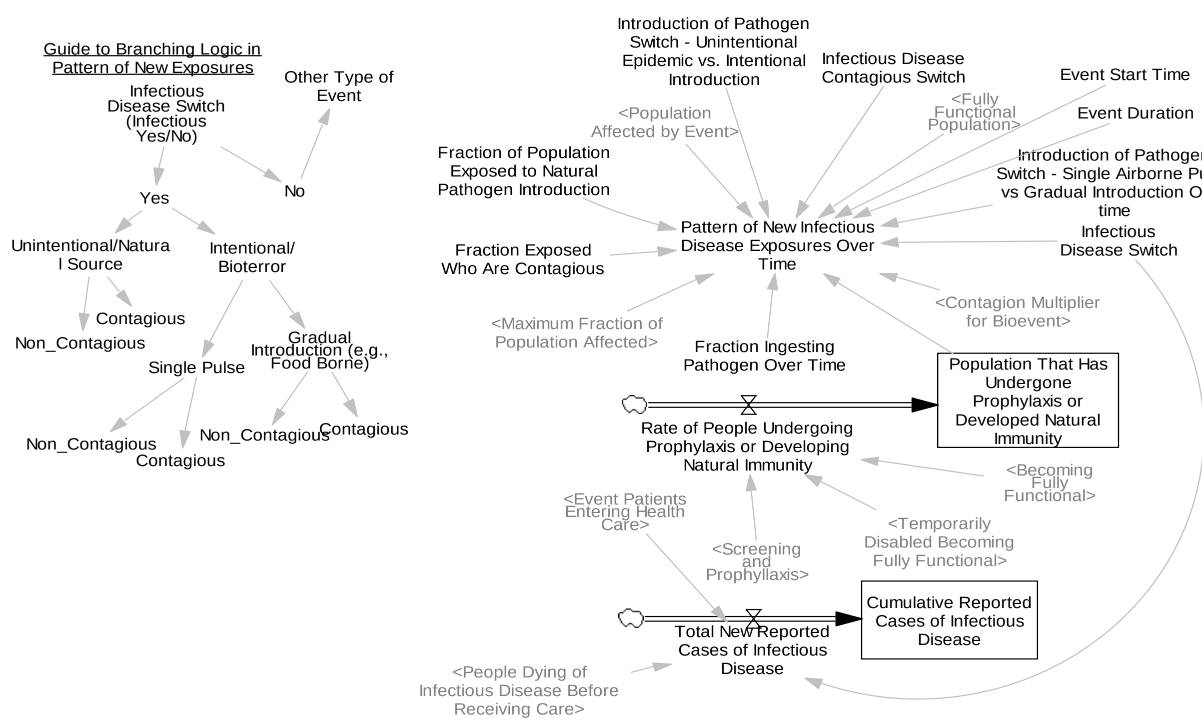

Figure 14: Infectious Disease Elements of Model

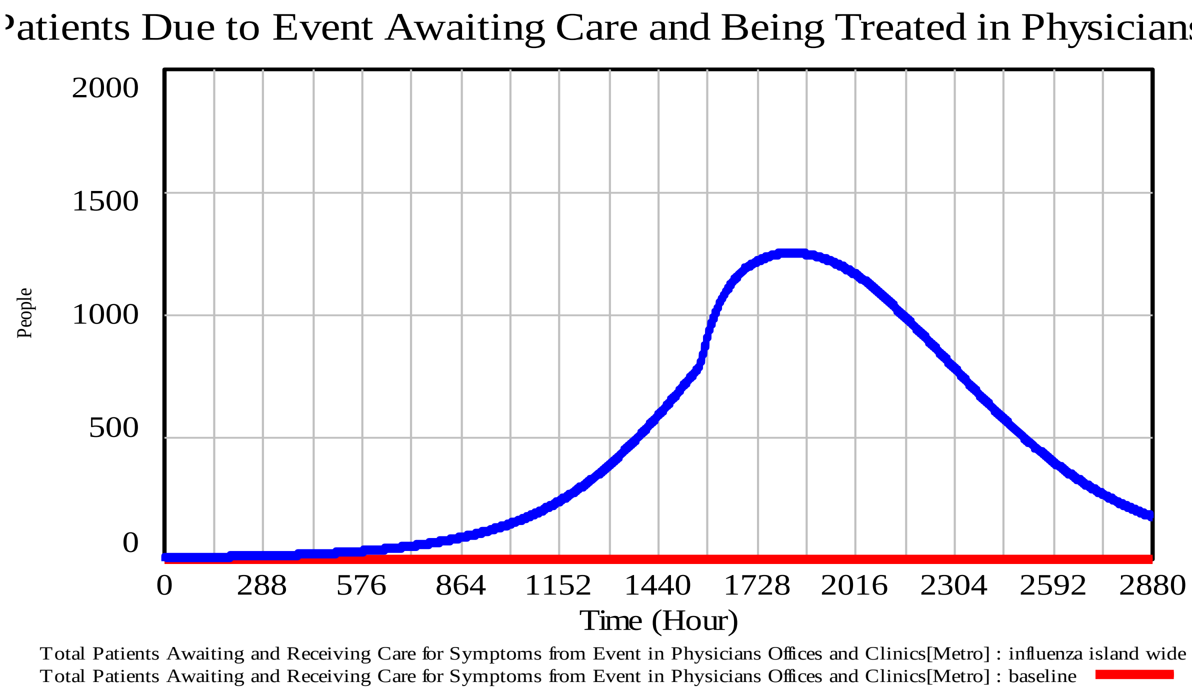

Figure 15: Influenza Simulation, Patients Awaiting Care and Being Treated in Physicians' Offices and Clinics

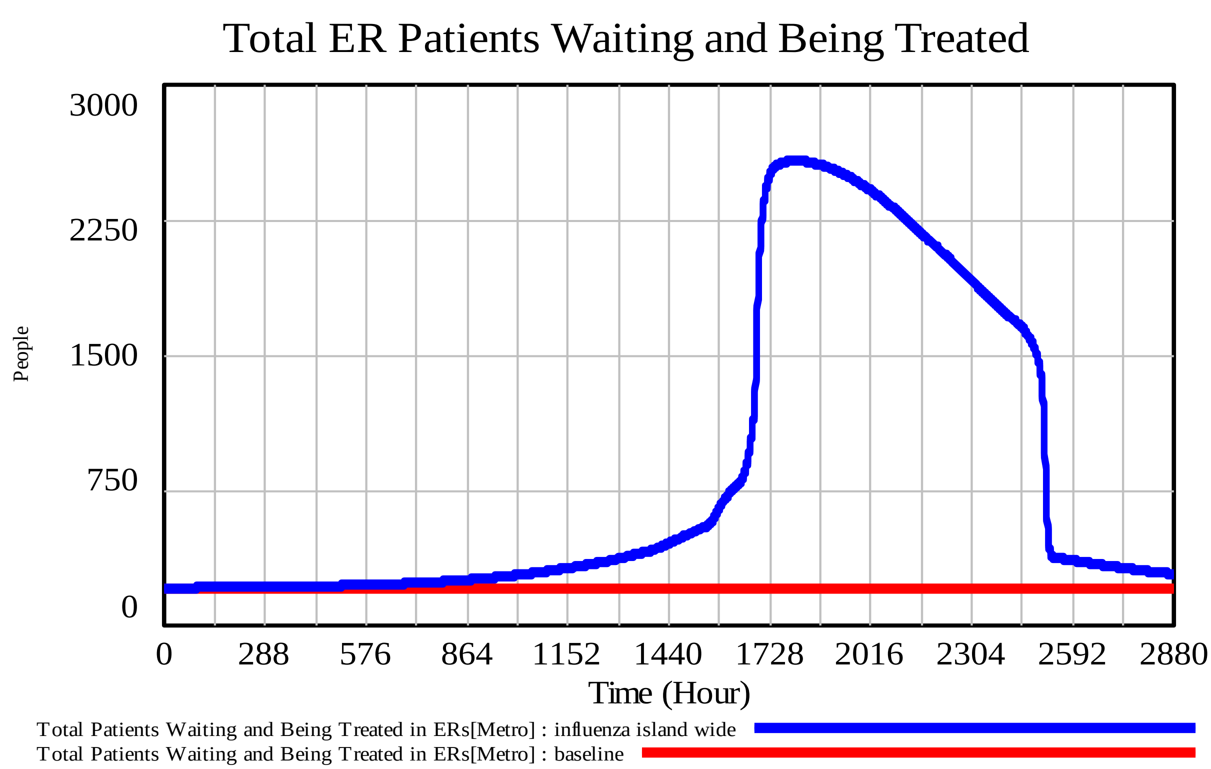

Figure 16: Influenza Simulation, Patients Waiting and Being Treated in Hospital ER's

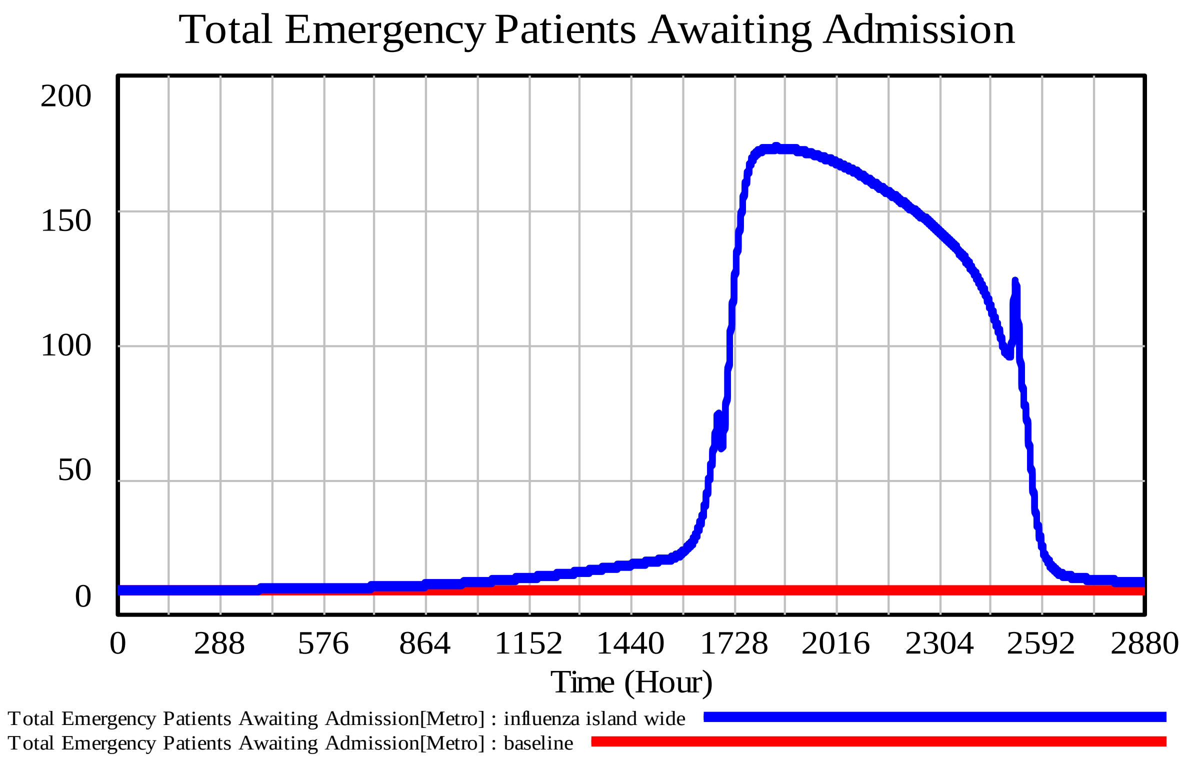

Figure 17: Influenza Simulation, Emergency Patients Awaiting Admission

Figure 18 shows the control panel for setting up influenza simulations. As with the Hurricane Control Panel, the left-hand side contains the various parameters for determining the size, speed of spread, and health care consequences of a pandemic. The Infectious Disease Switch and Infectious Disease Contagious Switch both need to be set to 1 to initiate pandemic. As indicated above, the Contagion Multiplier for Bio-event affects the rate and extent of spread of the disease. Other parameters such as the Fraction of Symptomatic Patients Seeking Care at Physicians' Offices and Clinics affect the volume and pattern of demand the pandemic places on the health care system.

The right-hand side contains various measures for mitigating the effects of the pandemic including parameters for creating additional capacity for prophylaxis (vaccination) to reduce the rate and extent of spread and additional personnel and beds to handle the peak health care demands that are created. A Users' Manual for the model describes how to make these changes.

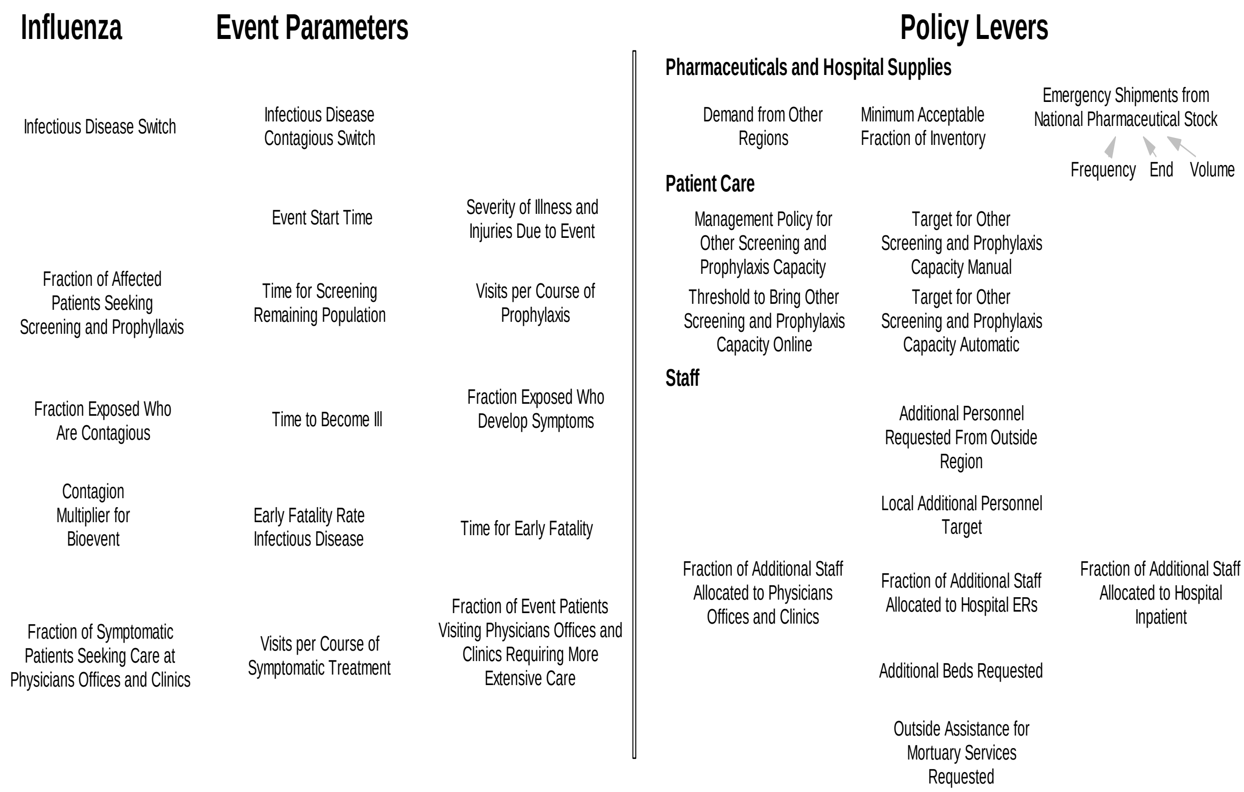

Figure 18: Influenza Control Panel

References

Hirsch G., (2004) “Modeling the Consequences of Major Incidents for Health Care Systems”, Proceedings of the 22nd International Conference of the System Dynamics Society, Oxford, England, July, 2004

Hoard, M., J. Homer, et al. (2005). "Systems Modeling in Support of Evidence-Based Disaster Planning for Rural Areas", International Journal of Hygiene and Environmental Health (208): 117-125.

LeClaire, R., G. Hirsch, et al. (2009), “Learning Environment Simulator: A Tool for Local Decision Makers and First Responders”, Proceedings of the 27th International Conference of the System Dynamics Society. Albuquerque, New Mexico, July, 2009

McNeill, K. M., et al, (2006), Surveillance for Illness and Injury After Hurricane Katrina --- Three Counties, Mississippi, September 5--October 11, 2005, CDC Morbidity and Mortality Weekly Reports (MMWR), March 10, 2006, 55(09): 231-234

Platz, E, H. Cooper, S. Silvestri, and C. Siebert,(2007) THE IMPACT OF A SERIES OF HURRICANES ON THE VISITS TO TWO CENTRAL FLORIDA EMERGENCY DEPARTMENTS The Journal of Emergency Medicine, Vol. 33, No. 1, pp. 39–46, 2007

Prosser, B. and C. Peters, (2010), "Directions in Disaster Resilience Policy", The Australian Journal of Emergency Management, (25): 3, 8-11, July 2010

PRSN--Puerto Rico Seismic Network (2015) available at http://redsismica.uprm.edu/English/research/geodesy/