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Pandemic Influenza Mitigation Strategies and Their Economic Impacts

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Pandemic Influenza Mitigation Strategies and their Economic Impacts

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The current avian influenza in Asia, Africa, and Europe has sparked discussions of a new human pandemic influenza perhaps hitting the world. While the current influenza is not spread by human-to-human contact—a necessary characteristic for a human pandemic—there is a potential that it may become so. Since the pandemic does not currently exist, it is not known what characteristics—such as infectiousness and death rate—the disease will exhibit. The study conducted by the Critical Infrastructure Protection Decision Support System (CIPDSS) explores the possible mitigation strategies and their effect on the US economy. Results show that while many people may be infected, the economic costs for the US are relatively low especially in comparison to past economic perturbations.

Introduction

Influenza is very common in the world with 36,000 people dying annually in the US[1] from seasonal outbreaks. More virulent strains have also occurred in the past and cause world-wide outbreaks. These outbreaks, called pandemics, can kill many millions of people around the world. More recent historic pandemics include the "Spanish Flu" of 1918 which killed at least 40 million people worldwide, 500,000 in the United States, and the "Asian Flu" of 1957 caused around one to four million[2] deaths worldwide and the "Hong Kong Flu" in 1968 killed more than two million people. In addition to the deaths, another global pandemic on the scale of 1918 will have severe economic effects. The Congressional Budget Office estimates that a severe pandemic influenza will cause a 4.5% decline in the U.S. GDP.[3]

All of these pandemics were originally an avian strain of flu circulating only in bird populations and not in humans—as is currently the case with H5N1 influenza virus in Asia, Africa and Europe. The 1918 "Spanish Flu" developed from a mutated strain of the virus H1N1. The 1957 influenza developed by reassortment from H2N2 and the 1968 "Hong Kong Flu" was caused by a strain of H3N2 which reassorted from H2N2.

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* The authors would like to thank the entire CIPDSS project team especially Dennis Powell, Rene LeClaire, Jeanne Fair, Brian Edwards, Perry Klare, Sharon DeLand, and Michael Wilson who helped model the influenza case shown in this paper. In addition, the authors would like to thank Jeanne Fair for her help with editing and fact-checking.

[1] http://www.cdc.gov. 1990-1999 figures.

[2] U.S. Department of Health & Human Services, Centers for Disease Control and Prevention (2006).

[3] http://www.cbo.gov/ftpdocs/72xx/doc7214/05-22-Avian%20Flu.pdf

Currently, the H5N1 avian virus is spread only in birds and is transmitted to humans mostly from direct contact with birds. Although there are some reports of human-to-human spread, the cases are isolated and mostly in families living in close quarters. The major concern with this virus is the death rate among humans that is currently 60%[4]. Although it is most likely that the death rate will decrease if the virus mutates or reassorts to become a human pandemic, the death rate for this unknown disease may still be high. Most experts predict that the death rate will be anywhere from less than 2% up to 15% based on previous pandemics. For example, the death rate of the 1918 pandemic was approximately 2%.

Government agencies and private industries worldwide are scrambling to prepare for a human pandemic caused by this virulent avian virus. Preparation involves not only the modeling the disease progression but also predicting the effects of mitigations available to the populations. CIPDSS is one of several programs that was tasked with this modeling effort.

In this paper we highlight the modeling efforts of Los Alamos and Sandia National Laboratories in identifying the economic impacts of a pandemic through the Critical Infrastructure Protection Decision Support System (CIPDSS) project. Several mitigation strategies are modeled using the CIPDSS tool to gauge resulting economic impacts. Mitigation strategies considered here include social distancing, targeted antivirals, and partially effective vaccines. The following sections will give an overview of the CIPDSS model, the epidemiological model, the economic impact model, as well as the resulting impacts from 7 mitigation strategies.

CIPDSS Overview

CIPDSS is a set of infrastructure models simulated almost entirely in system dynamics, coupled to a decision analytic tool designed to aid decision-makers with difficult choices between policies and mitigation strategies. CIPDSS is a joint modeling effort of Los Alamos, Sandia and Argonne National Laboratories sponsored by the Department of Homeland Security (DHS). The three labs are each the lead in one area although the work is completed collaboratively. Los Alamos National Laboratory has the lead for the metropolitan model (a model of the critical infrastructures from a generic metropolitan city), Sandia National Laboratories is the lead for the national model, and Argonne National Laboratory is the lead for the decision analytic tool.
The CIPDSS model consists of models of the major critical infrastructure as defined by DHS.

The individual infrastructure models are represented at each model scale (metropolitan and national) as is suitable: agriculture (national only), banking and finance, chemical and hazardous materials, defense industrial base (national only), emergency services (metropolitan only), energy, food (metropolitan only), information and telecommunications, postal and shipping, public health, transportation, water, and key assets. Because these listed infrastructures are not all inclusive of the US economy, other sectors are added in the models to help simulate the "real" workings of the infrastructures. For example, one additional model is the population—without people at work, all of these infrastructures grind to a halt. In addition, government and an economics "scorecard" model are included. For certain scenarios modeled, additional

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[4] World Health Organization., http://www.who.org. Reported as of March 20, 2007, there are 281 human cases with 169 deaths.

information—up to and including an entirely new model—is needed. An important example of this is the epidemiological model used in this study of pandemic influenza.

As mentioned above, the models are constructed using system dynamics and specifically in the commercial-off-the-shelf (COTS) system dynamics tool Vensim^{TM}. Each infrastructure, or sector, is modeled as a self-contained model with placeholder variables for the interdependencies with other sectors. A java tool written by project members, called Conductor, is used to integrate the necessary models for each simulation and create a single system dynamics model. The focus of these models is to represent the major stocks and flows of each infrastructure and the primary interdependencies with other sectors. For example, in the telecommunications model, phone calls are a major flow in the sector and are modeled including dropped calls, reattempts, and completed calls. In addition, interdependencies of the switching stations on telecommunications lines and the energy sector are included.

The model is designed to answer questions raised by decision-makers (mostly in city/county and national government) about what may occur in an event that may disrupt critical infrastructures. Some examples of events that have already been modeled by CIPDSS are: a telecommunications disruption, agricultural diseases, biological terrorism, a chemical release, hurricanes—including the spread of various diseases by contaminated flood waters—and pandemic influenza. The CIPDSS program has a goal of "order of magnitude" results and is therefore well-suited to comparisons of mitigation strategies—i.e. which mitigation strategy gives a significantly lower impact than others. As such, this pandemic flu study of seven different mitigation strategies is an ideal use of this model.

Epidemiological Infection/Disease Model

The infectious disease model is a modified Susceptible-Exposed-Infected-Recovered (SEIR) model. The stages are represented in a generic manner so that the model can be used for a large number of infectious agents by adjusting the input parameters appropriately. The model is written so that the user can enter either an R_0 value (the average number of people infected by a typically infectious individual) or a contact rate and infectivity rate with the R_0 value calculated as an output. For this study, R_0 was used as an input. Figure 1 shows displays the system dynamics diagram for a simple SEIR model with the resulting variable metrics highlighted in yellow.

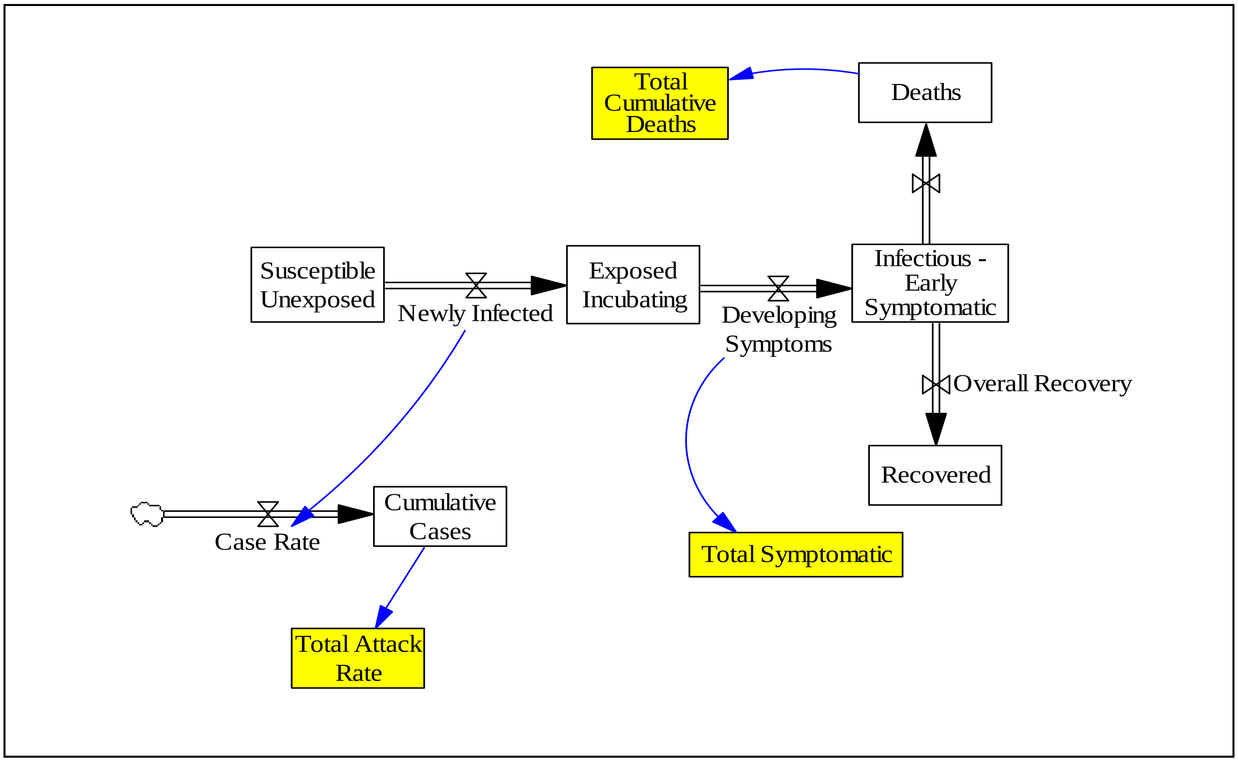

Figure 1. SEIR Disease Progression Model

Resulting variable metrics for the disease progression model are: Total Cumulative Deaths, Total Symptomatic, and Total Attack Rate. These metrics were used to validate our model against the results of other known disease progression models. The metrics then became inputs into labor and workforce models to determine the reduction in workforce.

The baseline scenario, representing a 1918-like influenza in the absence of interventions or mitigations, is described as follows.

- Clinical attack rate (i.e., the number of symptomatic cases divided by the age specific population)
    - Adult attack rate: 30% become symptomatic
    - Student attack rate: 40% become symptomatic
    - Fraction of infections that are symptomatic: 0.67
- Mortality
    - 2% of symptomatic cases, independent of age
- Fraction of symptomatic people staying home from work, school (Halloran, 2002)
    - 50% of all adults
    - 75% of all students
    - 80% of all preschool children

Additional scenarios (six total) included mitigations such as vaccines, self isolation, social distancing with masks, and quarantine. Most mitigations are input into the model before the “exposed incubating” stage of the model. The antivirals are administered after a person becomes symptomatic. The following (Table 1) describes the details of the baseline scenario plus the 6 mitigation scenarios considered in this pandemic influenza study.

Scenario	Description
Baseline	Adult attack rate: 30% Student attack rate: 40% Mortality rate: 2% of symptomatic cases Fraction of symptomatics staying home: • 50% Adults • 75% Students
Fear-Based Self Isolation ("Fear 40")	Baseline + 40% of total population self isolates (stays home) due to fear
NIH's Targeted Layered Containment (TLC)	Baseline + 60% of symptomatic cases stay home Antivirals given to symptomatic cases and their household contacts Symptomatic households are quarantined (30% compliance) Schools closed
NIH's TLC Lite	Same as TLC but with no school closure.
Antivirals	Baseline + Antivirals given to symptomatic cases and household contacts
Partially Effective Vaccine	Baseline + A partially effective vaccine is administered with 40% of vaccinated persons acquiring full immunity. The remaining 60% become infected but their illness is milder and they are less contagious.
Anticipated Intervention Strategy ("Nominal")	Baseline + Vaccine given to 5% of population 15% of total population self isolates due to fear 20% of schools are closed 15% social distancing with masks

Table 1. Scenario Descriptions

Economics Model

To estimate the magnitude of a possible pandemic influenza, a dollar value for economic impact is calculated within the CIPDSS models. For CIPDSS, the main figure in this estimate for the pandemic flu study is the lost gross domestic product (GDP).

GDP is a measure of productivity in the US. This model uses the GDP data from the 2004 estimate by the Bureau of Economic Analysis (BEA)[5]. The data from BEA is obtained by NAICS (North American Industrial Classification System) industry and then divided by the number of workers in each industry (also from BEA) to calculate the GDP that may be attributed to an individual worker. This number is then divided by 365 to get the average GDP contribution per worker per day.

Lost GDP is computed based on the Cobb-Douglas form of the production function: $Y = f(K, L)$. The change in GDP due to the pandemic influenza is given as $\Delta Y = Y_B - Y$ where (Y_B) represents the baseline GDP for the region and Y represents the GDP after the pandemic has taken place. In the CIPDSS model, capital (K) is a combination of available electricity (e) and available communications via wire-lines (w). Labor (L) is measured by industry and by state. The change in labor is the driving force behind the economic impacts for this study. Lost value added (Lost GDP) is represented as:

$$\Delta Y = Y_B - e^{\alpha} w^{\beta} L^{\gamma} \tag{1}$$

The values of (α, β, γ) are (.3, .001, .95) respectively showing both increasing returns to scale with a large share owing to labor. For this reason, a large absenteeism factor in the labor force will cause large economic losses for the economy (as seen in the results section).

The labor estimates in the model are derived in another “add-on” model for the population. This is directly influenced in this study by the disease model and the public health model. In this study, lost GDP is calculated from all workers who do not go to work (also called Unavailable Workers). This could be that they are sick, dead, self-isolated, or quarantined. We assume for this calculation that they do not work from home and therefore do not produce any output while in this status.

The GDP calculation is an estimate for the direct losses to the US economy over the time period studied. For this particular paper, the calculations were for the first year only. However, the following caveats apply: (1) although the events may cause structural changes to the economy, those changes are not evaluated in the economics model or in the rest of the CIPDSS infrastructure models (most of these changes will take more than a year to emerge); and (2) the ability to change business process and, for example, substitute inputs is limited during the

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[5] http://www.bea.gov/.

scenario and generally is not modeled—this ability may decrease the actual GDP losses. In this study, though, capital losses do not occur and losses are derived only from reduced workforce.

The economic impacts estimated in this analysis stem from reductions in output due to reduced workforce participation attributable to the pandemic. One calculation not included in these results is the agricultural costs due to losses in stocks of poultry in the case of an avian form of the influenza. This study did not calculate potential losses in this or other areas, partially because although still high, the human costs of a pandemic influenza would far outweigh agricultural concerns. Figure 2 depicts the Cobb-Douglass production function methodology for determining losses to the US economy in a system dynamics diagram.

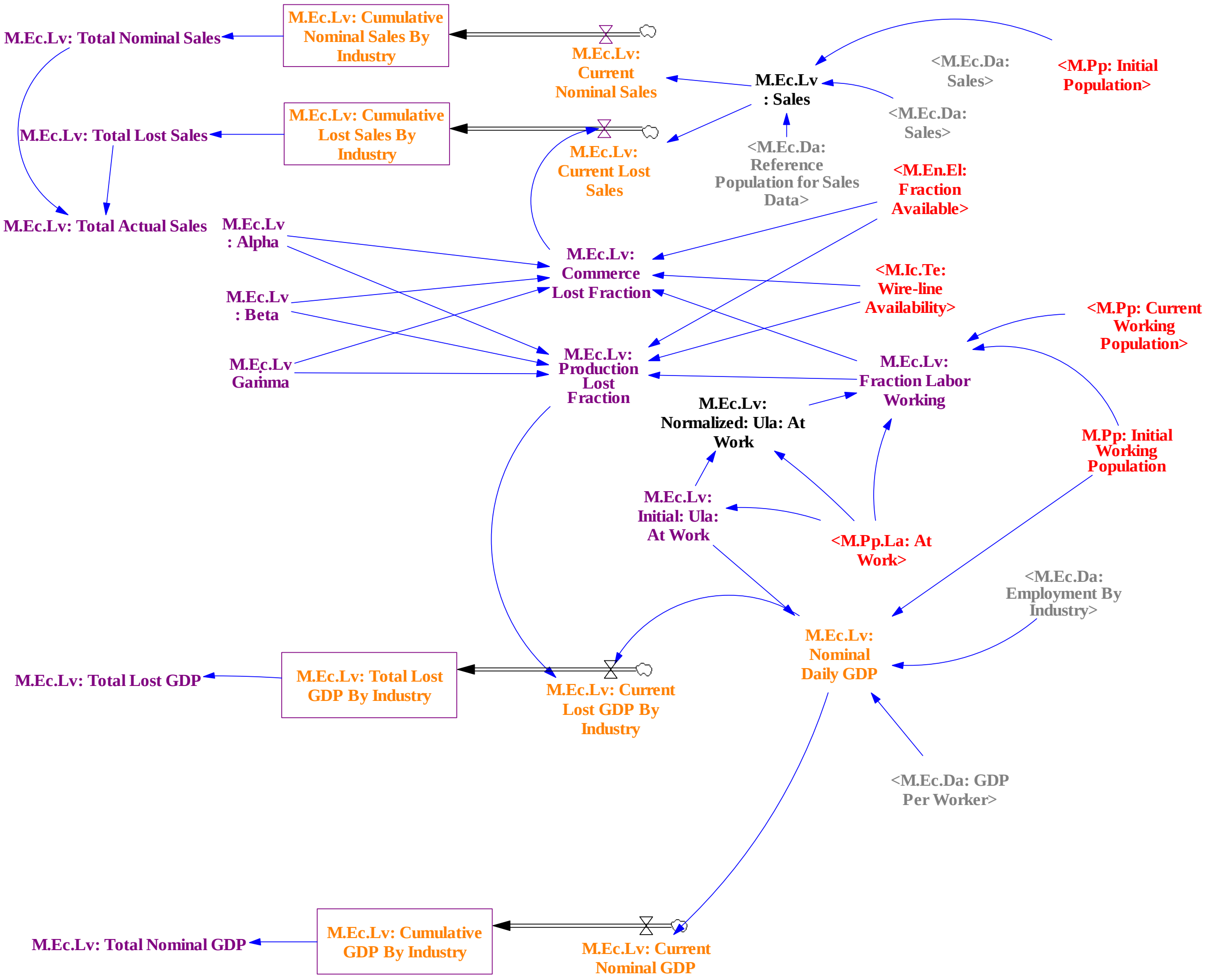

Figure 2. Economics Model in Vensim^{TM}

Mitigation Strategies

To simulate the seven scenarios that CIPDSS created (see Table 1 for detailed descriptions), several input variables for specific mitigations needed to be initialized at levels corresponding to the scenario run. The following Table 2 gives the initialized values for each of the input mitigation variables for each scenario. Some variables are the equivalent of an on/off switch (such as the use of masks) that activates a sub-model routine when switched "on". Other input variables have a specific value for initialization, such as "contact effectiveness."

Exogenous Model Parameters	Scenario 1 **Baseline No mitigations**	Scenario 2 **40% population worried well and fear isolates**	Scenario 3 **TLC Antivirals given, targeted prophylaxis, social dist**	Scenario 4 **TLC lite**	Scenario 5 **Antivirals only, targeted prophylaxis**	Scenario 6 **Partially effective (50%) vaccination**	Scenario 7 **Nominal Intervention Strategy**
Social Distancing (masks)	None	None	Yes	Yes	Yes	None	Yes
Self Isolation	None	Yes	Yes	Yes	Yes	None	Yes
Worried Well(parent to kid ratio)	On(.75)	On(4)	On(1)	On(.75)	On(.75)	None	On(1)
Vaccinations	None	None	Targeted	Targeted	Targeted	Mass	Mass
Avg contacts per case	20	20	10	1	2	20	20
Antivirals	None	None	Yes-unlimited	Yes-unlimited	Yes-limited	None	Yes-limited
Contact Effectiveness (fraction of contacts identified for prophylaxis)	.75	.75	.10	.078	.015	.75	.3
Targeted Prophylaxis	None	None	Yes	Yes	Yes	None	Yes
Death rate reduction from antivirals	n/a	n/a	100%	100%	100%	n/a	50%
Fraction antivirals applied to prophylaxis	n/a	n/a	94%	99%	90%	n/a	10%

Table 2. Mitigation Strategies

Results

Lost GDP results from the CIPDSS model for all of the pandemic influenza simulations performed are shown below in Figure 3.[6] These values represent the loss in GDP over a period of 1 year. As mentioned previously, the main impact on the GDP is absenteeism in the workforce (either due to death, sickness, or self-isolation). Although the number of deaths in the base case is higher than in any other case, the cases with the largest initial economic impact are the Fear-Based Self-Isolation (Fear 40) and the Anticipated Intervention Scenario (Nominal). These cases have much larger impacts because of the extra workforce absenteeism (see Figure 4 for a graph of absenteeism).

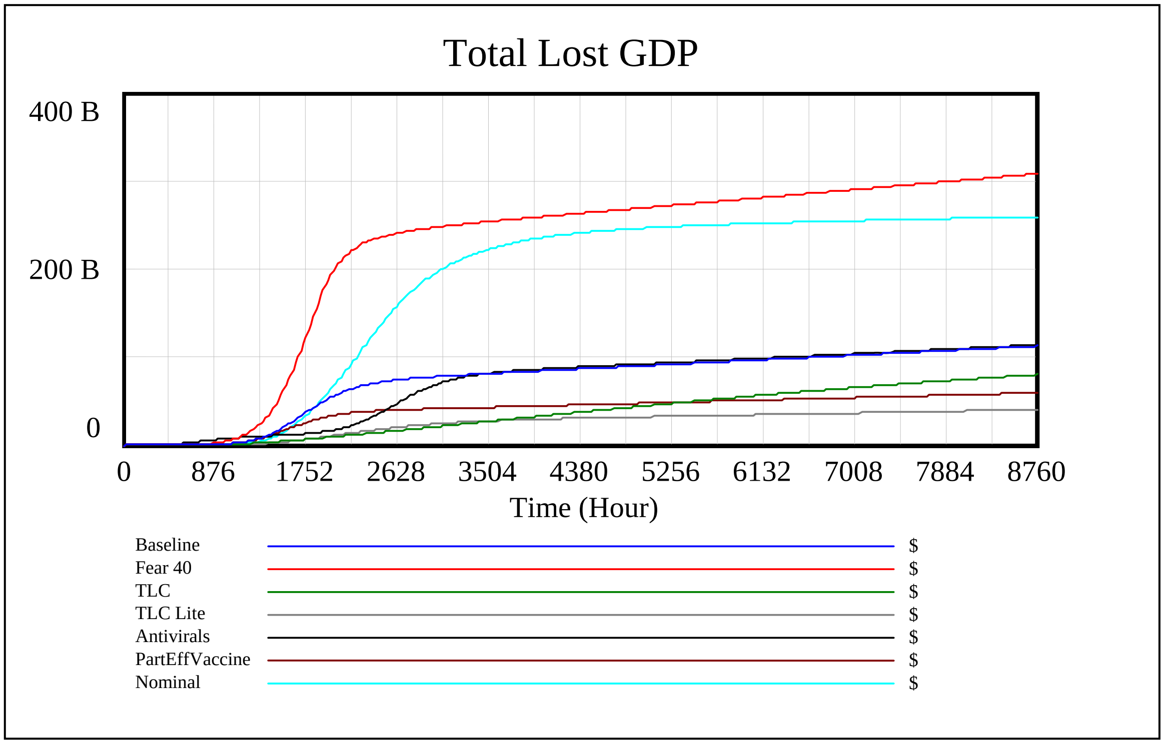

Figure 3: Total Lost GDP for each scenario

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[6] Results are from the Phase I portion of the CIPDSS Pandemic Influenza study. The CIPDSS model has since been revised and updated for the Phase II portion and now includes 24 scenarios and a slightly modified disease progression model. Please contact the authors if you are interested in Phase II results which differ slightly from Phase I.

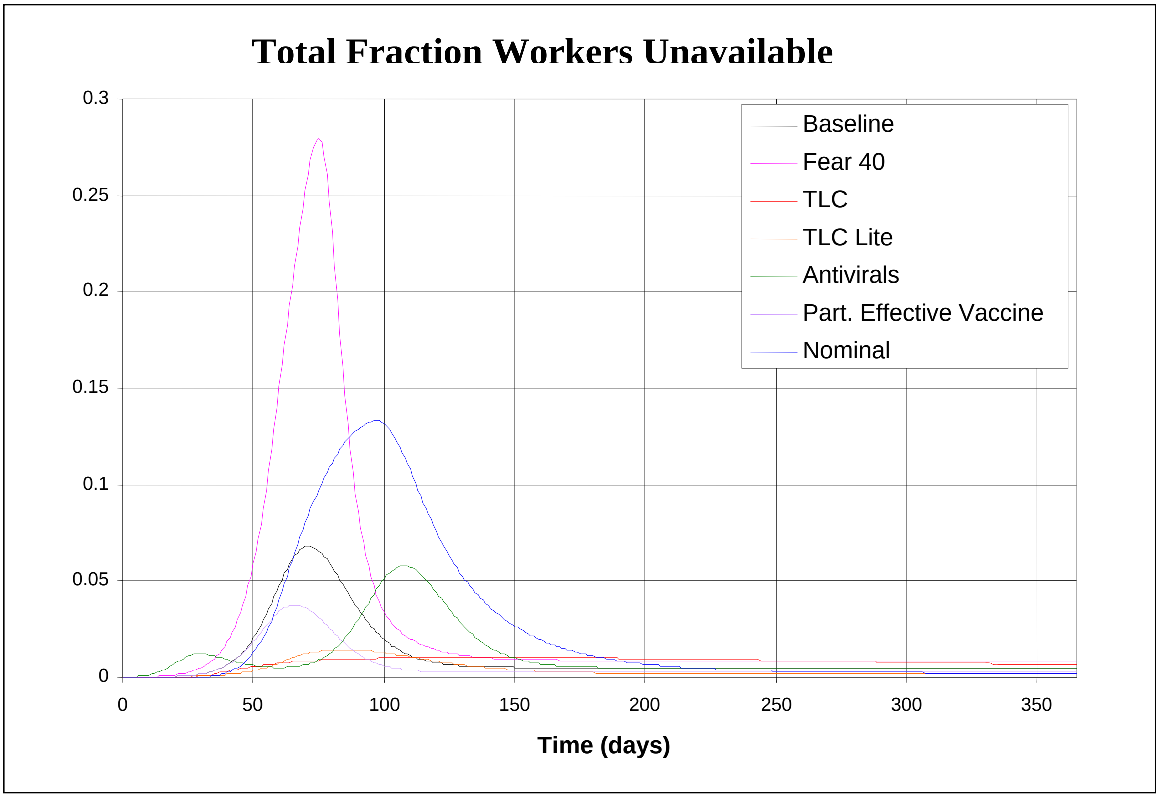

Figure 4: Total fraction of workers unavailable for each scenario

A loss of $300 billion[7] (the approximate value of loss in the Fear-Based Self-Isolation case) represents a 2.3% loss of GDP.[8] In the base case, the losses are just over $100 billion. This result corresponds to a loss of <1% of the GDP. These base case results also correspond with several other pandemic influenza studies (Blitzer, 2006; Burns, 2006; and Hanna, 2006).

Results of the other cases follow closely to absenteeism and death rates (see Table 3 below). That is, cases with very little to no self-isolation have much lower GDP losses than those with high rates. For example, the Partially Effective Vaccine case has a loss of approximately $60 billion (<1% of GDP) most of which is due to sickness and death (i.e. no self-isolation). Self-isolation was simulated in the Anticipated Intervention Strategy, though, and results from this are much higher at $260 billion (2% of GDP).

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[7] In 2002 U.S. Dollars.

[8] Based on an estimated $13 trillion of 2006 from the BEA.

	Base Incident	Fear-Based Self-Isolation	TLC	TLC Lite	Antivirals	Partial Vaccine	Anticipated Intervention Strategy
Number Illnesses	74 M	61 M	1.2 M	28 M	69 M	39 M	2.6 M
Number Hospitalized	8.1 M	6.6 M	140,000	3.0 M	7.6 M	4.2 M	280,000
Number Deaths	1.5 M	1.2 M	25,000	550,000	1.4 M	780,000	52,000

Table 3: Human Metrics for All Scenarios

These economic results are comparable in general magnitude to the first-year results found by another DHS-sponsored project conducted by Los Alamos and Sandia National Laboratories, NISAC (National Infrastructure Simulation and Analysis Center), using a different economic modeling framework from Regional Economic Models, Inc. (REMI) (Treyz, 1992). Almost all of these cases lie within the ranges of GDP percent losses generated from the REMI modeling. Furthermore, both models provide the same rank ordering of all the scenarios based on year 1 lost GDP. The TLC Lite scenario has the lowest economic impacts in the first year according to both NISAC and CIPDSS estimates; this reduction over Baseline is due to (1) a reduction in the number of ill, which reduces workplace absenteeism; and (2) a reduction in death, which reduces the losses to U.S. economic capacity.

This analysis was conducted without considering the costs of formulation, implementation, or enforcement of the actions that implicitly comprise the scenarios. The cost is likely directly related to the number of public policy actions involved with the scenario. For example, the nominal integration scenario calls for school closures, quarantine, 150 day vaccine development, the sum of which is likely to be costly.

Conclusions

The estimated cost of a pandemic influenza in the United States may vary widely depending on the mitigation policy (or policies) that the government and the people themselves choose to implement. The range of direct economic impacts for one year is $60 billion to $300 billion in GDP (or less than 1% to 3.2% of 2006 GDP). According to the study performed by the CIPDSS and NISAC teams, the most effective strategy in terms of minimizing losses to the economy would be the Targeted Layered Containment Lite (TLC Lite) scenario followed by the Partially Effective Vaccine and TLC scenarios. One important note, though, is that these strategies minimize GDP losses, but do not necessarily minimize deaths.

In order to more fully evaluate the best strategy for the government to employ, a benefit-cost analysis or decision analysis should be performed. These analyses would not only include the economic impacts, but the number of deaths and the cost of the mitigation strategies themselves. This type of analysis was not performed during this particular study.

Another important note to this study is the fact that the disease parameters are currently unknown as the pandemic itself does not yet exist. Possible parameters were used, but may not be correct. In the future, the NISAC and CIPDSS plan to complete a sensitivity and uncertainty analysis (as well as a decision analysis) that will explore the unknown parameters of the disease and the epidemiological model that will better inform the results of this study.

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