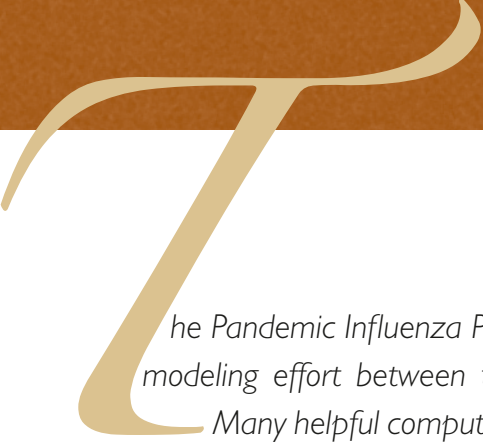# The Pandemic Influenza Policy Model, a Planning Tool for Military Public Health Officials

Brian H. Feighner, Sean P. Murphy, and Joseph F. Skora

*T*he Pandemic Influenza Policy Model (PIPM) is a collaborative computer modeling effort between the Department of Defense (DoD) and APL. Many helpful computer simulations exist for examining the propagation of pandemic influenza in civilian populations. We believe the mission-oriented nature and structured social composition of military installations may result in pandemic influenza intervention strategies that differ from those recommended for civilian populations. In addition, intervention strategies may differ between military bases because of differences in mission, location, or composition of the population at risk. The PIPM is a web-accessible, user-configurable, installation-specific, quick-response disease model allowing military planners to evaluate various intervention strategies. Innovations in the PIPM include expanding on the mathematics of prior stochastic models by using social network epidemiology, a user-friendly graphical user interface, utilization of DoD personnel databases to more accurately characterize the population at risk, and the incorporation of possible interventions, e.g., pneumococcal vaccine, not examined in previous models.

INTRODUCTION

A pandemic involving a novel respiratory pathogen is a significant, credible threat not only to the health of our nation but also to the operational effectiveness of the military forces defending our nation.[1–6] The most promising defense against pandemic influenza appears to be advances in vaccine technology, either in reduction of the time necessary to produce vaccines or in the creation of a universal influenza vaccine capable of conferring immunity to all strains of the disease via a single vaccine.[7–9] Great strides also have been made in another useful area, the field of computer simulation of infectious disease. Although not a panacea, these models are useful for planning responses to respiratory pandemics. Public health interventions used during a pandemic often

have significant economic, political, and/or legal ramifications. Additionally, the timing of the interventions, both implementation and cessation, may have dramatic impact on their effectiveness.[5,10–19] Computer simulation of disease spread under various intervention scenarios allows planners to evaluate the effects of public health interventions in a quantified manner, with all assumptions explicitly enumerated and open to discussion. Several excellent computer simulations have been developed for U.S. civilian populations.[5,6,10–15,17–30] Although helpful, these models lack the timeliness and/or the flexibility to incorporate the military-unique missions and requirements needed by military medical planners.

Given this state of affairs, the Office of the Secretary of Defense (Health Affairs) funded research on pandemic influenza by the U.S. Department of Defense Global Emerging Infections Surveillance and Response System (DoD-GEIS). DoD-GEIS, in turn, directed APL to create a disease-modeling tool for use at military installations. The goal of the Pandemic Influenza Policy Model (PIPM) project was to develop a tool that employed an easily understood, web-based interface, represented respiratory disease transmission at a military installation in a realistic manner, and displayed the effects of possible interventions in a timely manner. The primary emphasis of the PIPM project was to evaluate interventions that may maintain DoD operational readiness in the face of a respiratory pandemic.

In early project meetings, the PIPM team chose Fort Leonard Wood, Missouri, as the initial PIPM test site. Fort Leonard Wood is a U.S. Army post with an extensive Army, Navy, Air Force, and Marine training mission, with schools for Initial Entry Training (IET), schools for Advanced Individual Training, and schools for both noncommissioned and commissioned officers. An installation with a significant training mission was preferred because it encompasses one of the most important DoD-unique missions that not only affects operational readiness but also may have a critical impact on pandemic disease propagation itself. Furthermore, Fort Leonard Wood's isolated location with few transportation routes in or out meant that the initial modeling effort could focus on refining disease propagation within a virtually closed population. APL created the PIPM in a spiral development process with iterative feedback from DoD-GEIS project leaders, APL project members, and military collaborators at Fort Leonard Wood.

THE PIPM SIMULATION

The basic construct of the PIPM follows from the public health maxim termed the epidemiologic triad, which describes epidemics in terms of the interaction of "host, agent, and environment." This maxim conveys the concept that propagation of an epidemic in a population involves a complex interplay between the nature of the pathogen, the nature of the individuals in the population, and a myriad of environmental factors. In practice, the structure of the PIPM is that of two independent, yet interrelated, computer simulations.

Social Network Model

The structure of the population at risk for disease, in this case, the Fort Leonard Wood catchment area, is simulated by a social network model constructed from field observations at Fort Leonard Wood, the experiences of APL researchers, and the knowledge of Fort Leonard Wood collaborators. While some computer simulations model human interactions as random events, social network epidemiology models attempt to model human interactions more realistically by defining the ways in which different groups interact and how these group interactions result in individual contacts capable of spreading disease.[12,13,16,19,20,22,29,31,32] For example, at Fort Leonard Wood, soldiers in IET spend their duty days almost entirely with others in their training company (Fig. 1). On Sunday, however, these soldiers may attend chapel with other soldiers from different IET
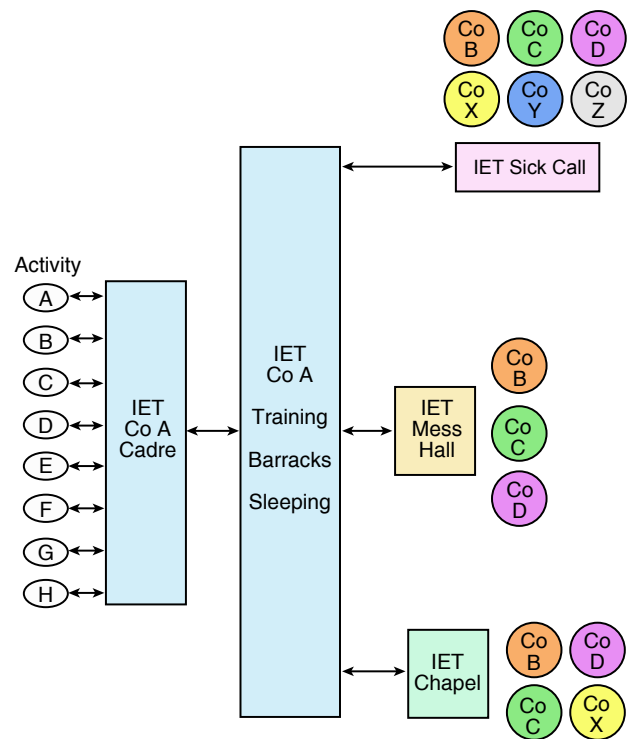
Figure 1. A simplified schematic of the social network of Company (Co) A soldiers in IET. Because of their highly structured day, they interact primarily with their cadre and fellow trainees in Company A. Exceptions include eating in the mess hall for all and attending chapel or presenting to sick call for some. Each of these exceptions exposes them to different populations of other trainees. The cadre, on the other hand, have extensive social interactions with the Company A trainees and many other social activities, both on and off post.

companies, but they still do not interact with recruits attending religious services at the 43rd Adjutant General (AG) Reception Battalion Chapel or with permanent party families attending services on or off post. The PIPM social network model attempts to represent how different groups of people carry out their daily activities and, importantly, with whom they interact during these daily activities.

Most models draw on U.S. census data to characterize the population at risk for disease. Currently, the Fort Leonard Wood population at risk is constructed from the monthly Fort Leonard Wood Post Population Report in the PIPM. This report is a detailed census of all units on Fort Leonard Wood. Twelve consecutive months of the report are used by the PIPM to accurately reflect seasonal patterns of population change on Fort Leonard Wood. The report also lists the monthly total of recruits processed through the 43rd AG Reception Battalion, which the PIPM uses to reconstruct the recruit population. Other demographic and health aspects of the PIPM population at risk, such as age, race, family composition, smoking status, and the presence of preexisting immunity, are assigned to individuals via stochastic draws of distributions derived from DoD data sources.

In future versions, the PIPM intends to use U.S. DoD Eligibility Enrollment Reporting System (DEERS) data to populate the PIPM simulation. DEERS data contain precise demographic information on every DoD health care beneficiary (active duty, retired, and their family members) as well as unit assignment of all active-duty individuals. Moreover, the DEERS database contains family linkages to every DoD health care beneficiary, allowing for the exact constitution of all military families, and both retired and active duty, eligible for care at DoD medical treatment facilities. We believe that the additional information content of the DEERS data is extraordinarily powerful. Instead of creating "families" of random size and composition based on census data, with the DEERS data we could reconstruct the reality of family "A" composed of a 30-year-old male Sergeant A assigned to unit "XYZ," his 32-year-old female spouse, and their 13-year-old daughter. At the time of publication, negotiations are still underway with the TRICARE Management Activity to allow use of DEERS data in the PIPM.

The social network epidemiology model in the PIPM could be considered an implicit network model. It goes beyond basic "Susceptible–Infected–Recovered" models by individually representing each person and their interactions at Fort Leonard Wood but does so implicitly, representing unique individuals via groups of people who share similar social networks and thus avoiding the need for supercomputer-level computational resources. Each group at Fort Leonard Wood (there are 243 groups in all) is assigned a schedule based on whether the current day is a weekday or a weekend/holiday. This schedule enumerates for each hour in the day the activity-place

where some percentage of the group will be interacting. An "activity-place" is a particular activity that occurs at a particular location. The location aspect allows the model to differentiate different groups sitting for a meal in different mess halls. Examples of activity-places include religious services at the 43rd AG Reception Battalion chapel and sick call at the Centralized Troop Medical Clinic. Furthermore, groups can be subdivided into an unlimited number of subpopulations, each drawn at random, that attend an activity-place different than the majority of the group. An example of this would be the 1% of soldiers per duty-day morning selected from each unit to constitute baseline sick call. The PIPM social network can be visualized as a long shelf containing many bins of balls, with the balls representing individuals on Fort Leonard Wood. Each bin represents one activity-place, in which the balls, i.e., individuals, may come into contact with each other. Underneath the first shelf of bins are 23 additional shelves of bins, one for each hour of the day. As each hour of the day progresses, the balls fall from one shelf to the next shelf of bins, re-sorting into different bins to represent the next hour of activity in and around Fort Leonard Wood. This process is repeated each hour of the day to construct the daily activities of all individuals on Fort Leonard Wood.

Each activity-place has an associated network type and range of contacts per hour. Network type specifies one or more of four basic network structures—ring, random, grid, and complete—that specify the structure of contacts per individual in the group during a particular activity and the contacts per hour that captures the number of "nose-to-nose" encounters, i.e., social interactions that afford equal opportunity of transmitting disease from one individual to another. For example, a ring network is a circle of individuals in which there is a decreasing probability of interaction as you move away from a selected individual. A ring network is used to represent classroom activity in the PIPM, where we believe the likelihood of transmission is greatest between immediate classroom neighbors. Another network type used in the PIPM is the random network, used, for example, for on-post activities that have a more random interaction component. Some activities have combinations of networks, e.g., a ring-random network. A ring-random network is common in recruits and trainees; this represents the effect of "battle buddies," a much-used system where two soldiers are charged with the care of each other for long periods of time.

One group at Fort Leonard Wood requires special mention. The 43rd AG Reception Battalion processes all recruits reporting to Fort Leonard Wood for training, totaling almost 28,000 individuals in FY2006. The 43rd AG Reception Battalion receives recruits each duty day and takes ~1 week to complete military in-processing and assignment to a training unit. Because the recruits come from all over the United States, undergo high stress, and

endure 16-hour days in a densely populated environment, the 43rd AG Reception Battalion is of prime interest for respiratory disease transmission. Because the Post Population Report and DEERS database have time lags of >1 week, they do not suffice for capturing the structure and activities of the recruits during in-processing. The current version of the PIPM approximates the transient nature of the 43rd AG Reception Battalion with a weekly "conveyor belt" function that receives recruits on a Monday and disperses them to various training units on the following Friday.

Disease Model

Once the social network model is established and the individual demographic and health characteristics have been assigned, the PIPM disease model then simulates the transmission of respiratory disease on Fort Leonard Wood. The PIPM disease model is a five-stage model, dividing individuals into one of five groups: (*i*) susceptible, (*ii*) latent infection, (*iii*) early transmission, (*iv*) symptomatic, and (*v*) resolved disease. The time that each individual spends in each stage, if infected, is determined by stochastic draws of a lognormal distribution that differ by age, group, and risk classification. An important factor in the spread of influenza is the ability for an infected individual to spread the disease before he or she has any symptoms (or to spread the disease even if they never have symptoms). To allow for the possibilities of presymptomatic, asymptomatic, and symptomatic disease transmission, the disease-transmission efficiency of presymptomatic and asymptomatic individuals is set to 50% of the default efficiency of symptomatic individuals. Thus, to create an individual with asymptomatic disease, the time spent in the early transmission stage would be increased and the time spent in the symptomatic stage would be decreased to zero hours.

When an infectious individual interacts with another individual in the disease model, the probability of transmission is guided by many factors. First, as noted above, the infectiousness of symptomatic individuals is greater than that of individuals with asymptomatic infection or infected, presymptomatic individuals. Next, the probability of transmission is guided by host characteristics such as inherent immunity and interventions, e.g., antiviral prophylaxis, that may be present in that individual. Lastly, the probability of disease transmission is then driven by the number of interactions between the diseased and those without disease.

When disease transmission occurs, the progression of disease in each individual is determined by stochastic draws; the values of these draws also are affected by the individual's personal and environmental characteristics. As the infection progresses, an individual's behavior may change in two ways. First, their time at home, i.e., away from work or duty, increases for some number of days. In addition, their health-care-seeking behavior increases. The probability of disease complications, perhaps leading to hospitalization and/or death, is determined by stochastic draw influenced by individual characteristics such as the presence of a high-risk medical condition, a history of smoking, prior immunizations, and treatment within 48 hours of symptoms with antiviral medications. The construction of the population at risk is performed in a Monte Carlo manner with typically 10–100 iterations. The number of runs required for reasonable result convergence is still an issue being examined. The PIPM runs for a 0- to 99-day simulation, with a default value of 60 days.

Public Health Interventions

Public health interventions are actions requested of or imposed on members of the public in an effort to decrease the spread of an infectious disease. Possible public health interventions in the PIPM are divided into three basic types: (*i*) those that decrease opportunities for disease transmission, (*ii*) those that decrease efficiency of disease transmission, and (*iii*) those that decrease the severity of disease given infection. Examples of interventions that decrease opportunities for transmission include isolation, quarantine, and closure of public schools or other public places. Interventions that decrease the efficiency of transmission include facial masks, respiratory etiquette, or antiviral prophylaxis. Interventions that may decrease the severity of disease include treatment with antiviral medications, antibiotic therapy, immune therapy, or prior immunization against pneumococcal pneumonia. These interventions also are characterized as global (applied to all individuals in the model), unit-specific, or geographically specific interventions. The PIPM user not only assigns which populations or subpopulations receive which public health interventions, but also, as noted above, can accept the default values for intervention effectiveness or assign effectiveness values of their choosing.

Most public health interventions are turned off in the PIPM by default and must be turned on by the user. Importantly, the user must specify not only which day of the simulation the intervention is implemented but also the day on which the intervention is terminated. Concerning the start date of public health interventions, the simulation begins on "Day 0" with the infection of the first individual(s), and it would be unusual to become aware of any significant illness before Day 2 of the simulation. Several interventions have a window during which they have varying degrees of effectiveness but after which they are ineffective. By running various scenarios with different times of implementation, planners can gain a better understanding of the deadlines for implementing a given intervention, as well as when to discontinue an implemented intervention.

PIPM Variables

There are three levels of variables in the PIPM. The first level consists of the variables that require PIPM user input for each run (basic level). For example, the user must identify the author and the name of the run and enter their e-mail address to enable a PIPM simulation to begin. Two additional levels of variables (advanced and system level) have been set to default values gathered from the medical literature or other widely accepted influenza models. Some values, such as the percentage of active-duty smokers by age and gender, come from sources such as the DoD Worldwide Survey of Health Behaviors.[33] The PIPM developers believe that the user should feel free to alter the values of these variables to better represent their population at risk. The entry forms for the advanced variables are color-coded yellow to indicate the need for caution when changing their values. Similarly, the entry forms for the system variables are color-coded red to indicate that they should be changed only with extreme caution.

Although there are some fixed aspects of the PIPM, e.g., it can only be seeded with one novel pathogen at a time, a key aspect of the PIPM is its flexibility. The user may alter the values for any variable in the disease propagation model. This obviates many of the arguments associated with disease modeling, such as disagreements over the efficiency of disease transmission given interaction or the effectiveness of antiviral medications, vaccines, or other interventions. The user may adjust all of these variables in the disease model as they see fit for their population. A future version of PIPM may contain disease parameter templates with predefined transmission parameters representative of different respiratory pathogens such as smallpox or severe acute respiratory syndrome (SARS).

Information Technology

The underlying technology running the PIPM is a combination of a Java Enterprise Edition (JEE; Sun Microsystems) website and a Mathworks Matlab® simulation. For security pur-

Figure 2. The web interface also allows the user to view the results of a run, providing a variety of tables, charts, and graphics analyzing the run output.

Figure 3. A series of drop-down boxes are used to select the desired values for variables for the PIPM run.

poses, the web interface is fronted with an Apache Web Server, using HTTP over Secure Sockets Layer (SSL) to guarantee privacy on the wire, similar to online merchant and banking sites. Behind this, the Apache Tomcat JEE servlet container provides the web interface with which the user interacts, requiring user authentication against a known list of users before allowing access. The web interface provides the capability to characterize a simulation run through the configuration options, and then it adds the run to the queue to be processed. The simulation does not actually run in the web interface, to provide for greater scalability and stability. When the model simulation is completed, the web interface also allows the user to view the results of a run, providing a variety of tables, charts, and graphics analyzing the run output (Fig. 2).

The model runs themselves are actually processed asynchronously to the web interface by using Matlab®. A Java application, running as a Windows service, watches the database for queued runs, pulls the run from the queue, prepares the input data, and starts Matlab® to run the simulation. This service monitors the model

running in Matlab®, updating the run's status on the website (so the user can track progress on long runs), and it loads the results into the database when the simulation is complete. To help ensure uptime and raise awareness of system problems, another Java service runs on a separate server, monitoring the availability of the website and notifying the project team in the event of an outage.

Creating a PIPM Simulation

To create a new scenario for simulation, the user assigns values for the variables that describe the epidemiology of the pathogen in the disease model. Using a series of drop-down boxes, the user selects the desired values for variables for the PIPM run (Fig. 3). If the user wishes, he or she may alter the values of other variables, such as incubation period or age-associated preexisting immunity, by overriding the default values of the model. To quickly modify a previous run, the user can copy a previous scenario from the archive and make slight changes to it. When the scenario is set to his or her satisfaction, the user submits the run to the PIPM server. Currently,
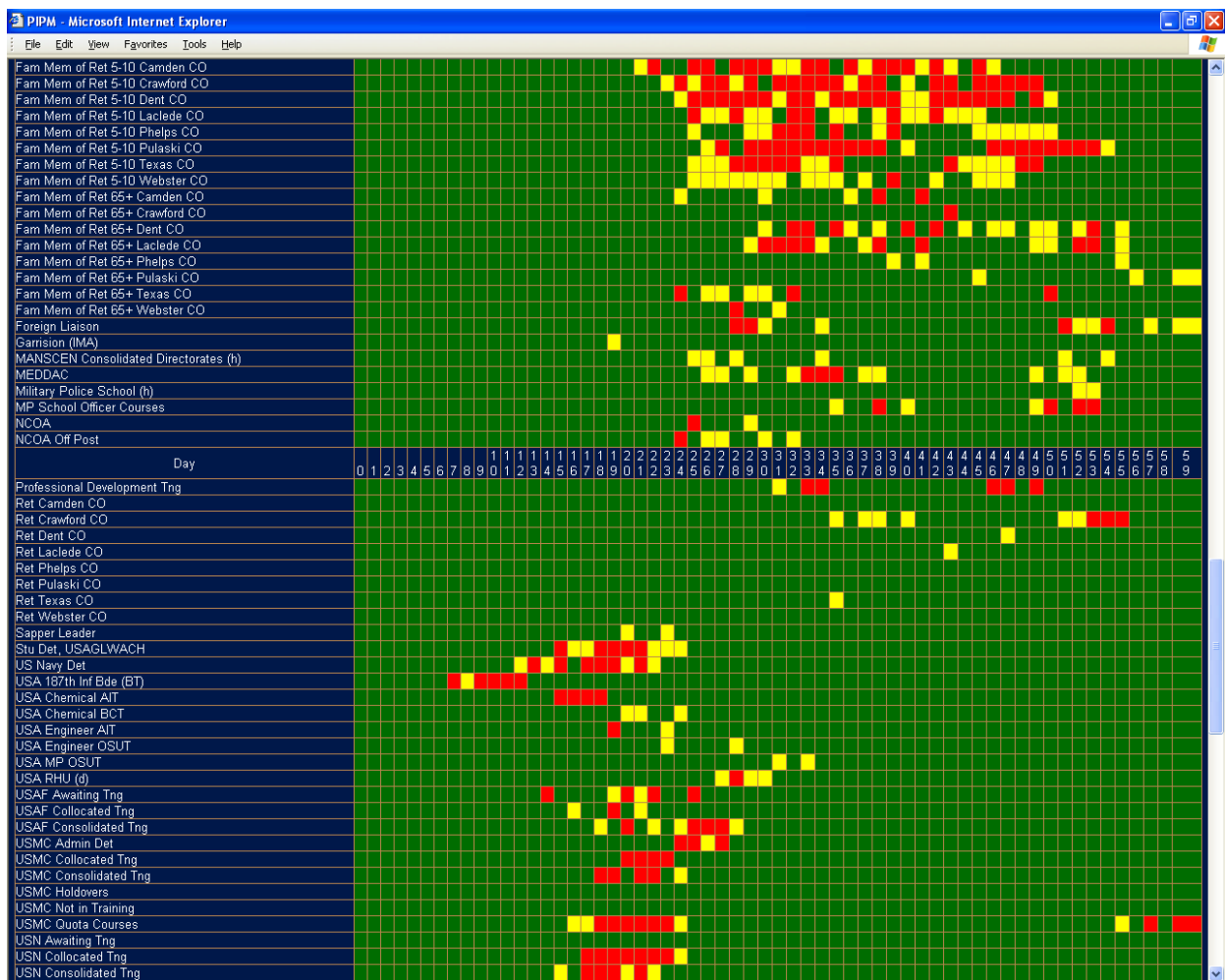

Figure 4. The summarized results of a PIPM run are presented with a green/yellow/red dashboard of unit readiness.

a PIPM run takes between 2 and 8 hours, depending on the scenario and the number of iterations requested by the user. When complete, the PIPM website sends an e-mail notifying the user of the submitted run results. The user can then review the results from any computer with Internet access. Graphs and diagrams in the results may be downloaded as .jpg files for inclusion in Microsoft PowerPoint or other presentations. A copy function that exactly duplicates the selected run is available, allowing for quick resubmissions of runs with only slight modifications. The website displays pertinent information on each run along with summary statistics of the run. This function is particularly helpful when multiple authors are using the PIPM because different authors may use different naming schemes for their PIPM scenarios.

PIPM Output

Output from the PIPM simulation includes several measures of the outbreak. At the top of the output is a measure of total mission readiness for all units on Fort Leonard Wood. In Fig. 4, green indicates mission readiness for units that are >85% strength, yellow indicates mission readiness for units that are 75–85% strength, and red indicates mission readiness for units that are <75% strength. The strength levels corresponding to each color level may be changed by the user. Mission readiness also is expressed for civilian groups, e.g., family members living on post aged 5–10 years. Although these groups do not have a "mission," their values can be used to estimate other parameters such as school absenteeism. Below the mission-readiness display are several epidemic curves of total new onset of illness by day, total new hospitalizations by day, and total mortality by day. These results also may be viewed for a specific unit or group of persons by using a drop-down menu box. In Fig. 5, PIPM results are presented in a number of graphical and tabular formats that can be organized by the user and exported to Microsoft products for use in presentations.

Deployment of the PIPM

In September 2007, COL Mimms Mabee, Fort Leonard Wood Public Health Emergency Officer, and Brian
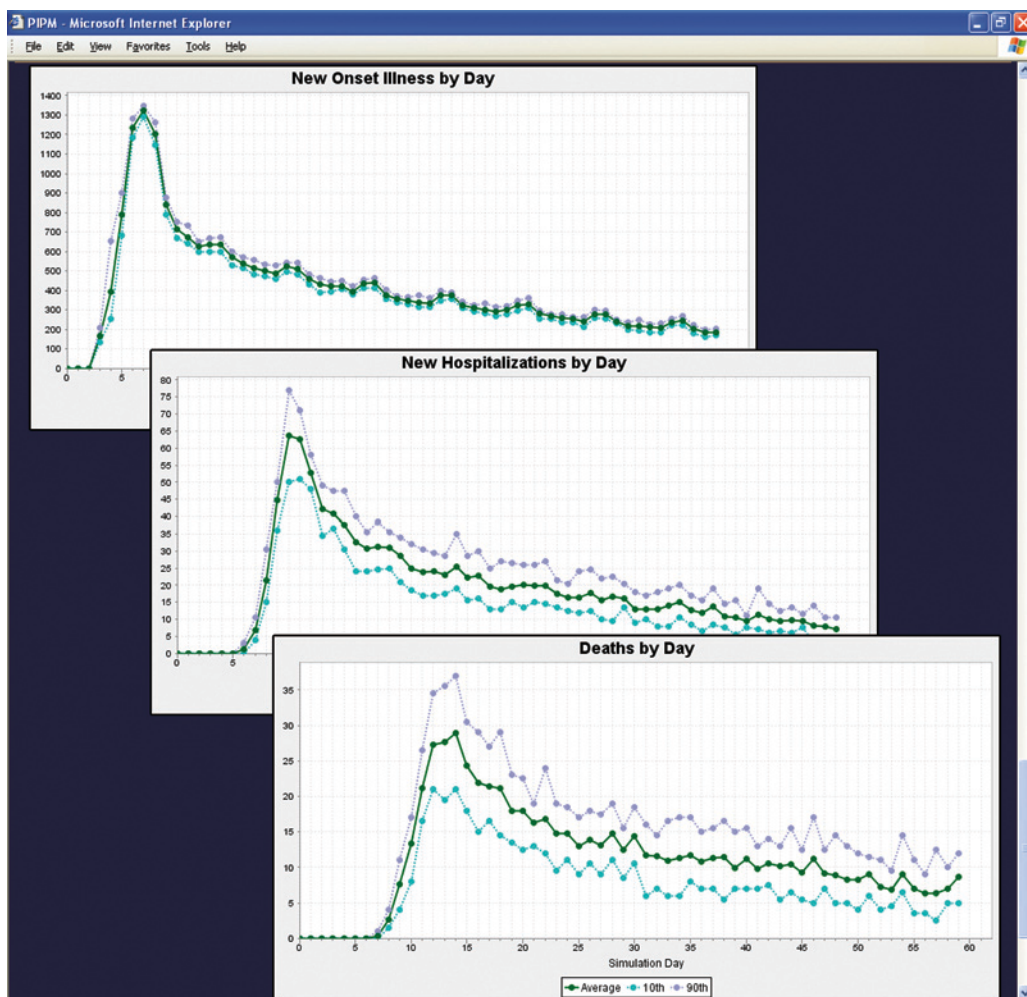
Figure 5. PIPM results are presented with epidemiologic curves of new illness, new hospitalizations, and deaths over time for each unit or the population as a whole.

Feighner briefed the Fort Leonard Wood Command Group on the project. The PIPM is now in use by Fort Leonard Wood military planners for exercise, planning, and response purposes. As COL Mabee explained to the Command Group, not only can her office use the PIPM to conduct exercises to evaluate their contingency plans, but the PIPM also provides an objective framework from which intervention recommendations can be made in the face of an impending pandemic.

CONCLUSION

The PIPM project, a joint venture of APL and the DoD, has established a rapid, web-based computer simulation model of pandemic influenza at Fort Leonard Wood, Missouri. Fort Leonard Wood military and medical planners can now analyze the impact of various public health interventions on the transmission of pandemic influenza on their post. Although primarily a tool against pandemic influenza, the PIPM is flexible enough to accommodate other novel respiratory pathogens. The PIPM incorporates key disease-transmission variables found in existing models constructed for civilian use, as well as a myriad of DoD-unique variables resulting from training missions, deployments, and other activities not found in the civilian sector. Outputs from the model include epidemiologic curves showing projected disease propagation through a particular military installation, projected morbidity and mortality, and projections of green/yellow/red operational readiness. Using the PIPM, military planners are able to evaluate the impact of the pandemic on their populations and their operational readiness. With our original goal met, our attention now turns to several concerns. First, the model itself must be refined, evaluated, and validated. Work is also underway to generalize the PIPM for use at other U.S. military installations. Further refinements to the PIPM include generalizing the PIPM to simulate other diseases and streamlining the process that determines the best intervention strategies for a given pandemic scenario.

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