Disseminating Emergency Preparedness Planning Models as Automatically Generated Custom Spreadsheets

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When public health officials requested OR models to help county health departments across the United States create plans for dispensing medications and vaccines during emergencies, we developed capacity planning and queueing network models. We then faced the challenge of distributing these models to people with minimal experience with OR techniques and no resources for acquiring and learning new software. To eliminate the most significant obstacles, we decided to use spreadsheets. We created a spreadsheet application that runs Visual Basic for Applications (VBA) macros to generate customized analytical models without the assistance of an OR professional; thus, users could evaluate a wide variety of plans. Developing spreadsheets for this type of application differs significantly from end-user modeling and typical spreadsheet applications. The software is available on our website for public health emergency preparedness planners to download.

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M ontgomery County, Maryland, is home to one of eight Advanced Practice Centers (APCs) for public health preparedness. The APCs customize and package innovative tools for other local public health agencies to strengthen their bioterrorism planning and response capabilities. The Centers for Disease Control and Prevention (CDC) funds the APC programs; the National Association of County and City Health Officials (NACCHO) administers the programs and maintains an online clearinghouse of APC preparedness tools for local public health agencies (National Association of County and City Health Officers 2005). The APC's long-term goal is to create and disseminate a broad set of methods and guidelines to help county health departments create, assess, and improve their emergency preparedness and response plans.

Emergency preparedness includes carefully planning mass-dispensing and vaccination clinics, which we refer to as points of dispensing (PODs). When a clinic begins operations, the health department must assign the correct number of workers to various roles. It must also consider the capacity of each clinic (i.e.,

the number of residents that it can serve per hour) and the number of minutes that residents will spend in the clinic (i.e., time in system, flow time, and throughput time). Clinic capacity affects the number of clinics needed and the total time needed to vaccinate an affected population. The time in system affects the number of residents who will be inside the clinic waiting for treatment; too many residents in the clinic could cause crowding and confusion.

Evaluating clinic plans requires the use of OR models, such as capacity planning and queueing. We developed discrete-event simulation models and capacity planning and queueing network models to improve clinic planning in an ongoing collaboration with the University of Maryland (College Park) and the Montgomery County (Maryland) Public Health Services (PHS). Aaby et al. (2006b) provide additional information about these models.

In this paper, I discuss the challenge of distributing these models to people with minimal experience with OR techniques and no resources for acquiring and learning new software. Providing the models in a format they could use was critical. The options we

evaluated included publishing a report that presented the mathematical models, developing an original piece of software, creating spreadsheets for common clinic layouts, and providing discrete-event simulation models. We decided to develop a spreadsheet application that allows users with no experience in building OR models to create and use customized, analytical capacity planning and queueing network models—without the assistance of an OR professional. Public health emergency preparedness planners can download the software from our website http://isr.umd.edu/Labs/CIM/projects/clinic/.

Emergency Preparedness Planning

Following the terrorist attacks of September 11, 2001, public health officials at the US federal, state, and county levels accelerated efforts to plan their responses to events such as bioterrorism attacks (e.g., the intentional release of smallpox or anthrax) and outbreaks of contagious disease (e.g., pandemic influenza). The resulting plans often call for PODs (Centers for Disease Control and Prevention 2002). Public health officials must create a set of clinic designs to prepare for a range of bioterrorism and contagious disease emergencies.

In the worst-case scenario (e.g., terrorists release a smallpox virus into the general population), everyone in the affected area would require vaccination within a few days. Kaplan et al. (2002) compare vaccination policies for responding to a smallpox attack; they show that in the most likely attack scenarios, mass vaccination would result in many fewer deaths than other procedures. For example, Montgomery County, Maryland, would need to vaccinate nearly one million people. To vaccinate so many people in a short period, it would have to set up PODs at designated sites throughout the county.

At a typical POD, residents go to the triage station outside the clinic building. Members of the triage station staff ask residents whether they have any smallpox symptoms (e.g., a rash or fever) or whether they have been exposed to the smallpox virus. Other staff members escort symptomatic residents to a symptoms room to consult with a doctor. Residents exposed to the virus (but otherwise healthy) go to a holding room to wait for medical attention. These rooms are separated from the rest of the POD to reduce the risk
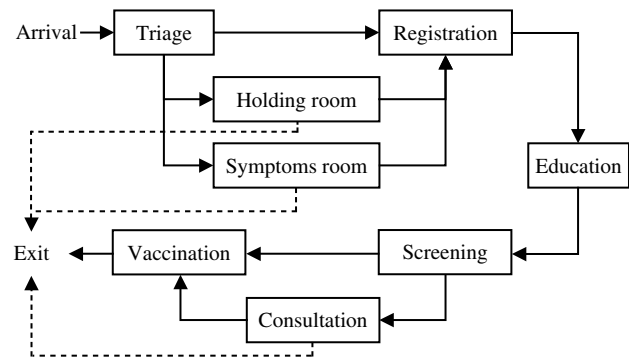

Figure 1: The flowchart shows the flow of residents in a typical POD; the dashed lines show residents who exit the clinic without receiving vaccinations.

of infecting others. After consulting with a doctor, infected residents exit the clinic and go to a hospital; healthy residents are allowed continue to registration (Figure 1).

After entering the clinic, residents obtain registration forms and printed information on smallpox at the registration station. The staff includes translators for non–English-speaking residents. Residents then proceed to the education station—a set of classrooms in which they watch informational videos about the smallpox vaccine and fill in the registration forms. The education station staff checks the registration forms for completeness. Residents then walk to the screening station.

At the screening station, medical personnel check their registration forms and direct residents who, based on their medical histories, could suffer from vaccination complications to the consultation station. The remaining residents sign consent forms and go directly to the vaccination station.

At the consultation station, residents discuss possible complications with a doctor. Those who refuse the vaccination receive an information sheet and leave the clinic; public health officials will monitor them. Those who decide to be vaccinated sign consent forms and go to the vaccination station.

At the vaccination station, a nurse verifies that the consent form has been signed and witnessed and vaccinates the resident. Another staff member reviews a post-vaccination information sheet (i.e., what to do after the vaccination) with the resident; the resident then leaves the clinic.

Choosing Spreadsheets

We began our analysis of clinic planning with a simulation study to evaluate alternative clinic designs (Aaby et al. 2005). We designed and built a discrete-event simulation model of the POD based on data that we collected during a full-scale exercise. After validating the model with our results, we used simulation models to evaluate alternative clinic designs and operational policies. Because discrete-event simulation models require specialized software that public health officials do not have, we decided to develop analytical capacity planning and queueing network models and to implement them as spreadsheets. We considered—but discarded—other options, as discussed below.

First, we developed two analytical capacity planning and queueing models: one for vaccination against a contagious disease (e.g., smallpox, as Figure 1 illustrates), and another for dispensing medicine (e.g., antibiotics for anthrax). Public health officials who reviewed these models concluded that these two models did not offer sufficient flexibility to evaluate a wide range of reasonable clinic designs. Therefore, we created software, which we called the Clinic Planning Model Generator. It can generate a spreadsheet-based, capacity planning and queueing model for a customized clinic configuration. The software is available at http://www.isr.umd.edu/Labs/CIM/projects/clinic/.

Planners can use the clinic planning models to determine the number of staff members they need to satisfy capacity requirements and to design clinics to avoid unnecessary congestion. Public health professionals have validated the models, which are based on data that we collected from clinic exercises.

Public health professionals throughout the United States have downloaded the software and used it to help create plans for PODs. Aaby et al. (2006a) describe the use of the Clinic Planning Model Generator for planning PODs for pandemic influenza. CDC recommended the model's use for pandemic influenza preparation (Centers for Disease Control and Prevention 2006).

Software Structure

The Clinic Planning Model Generator software consists of two Microsoft Excel workbooks: the clinic
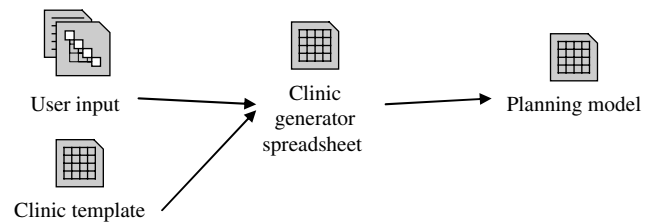

Figure 2: The Clinic Planning Model Generator software accepts user inputs and modifies the clinic template file to create a custom clinic planning model that the user can modify as desired.

generator and the clinic template. Its documentation consists of a user guide and the sample clinic model, which is also a Microsoft Excel workbook. We implemented the code in the workbooks using Visual Basic for Applications (VBA) macros; they run when a user opens the workbook and clicks on buttons in the spreadsheet. The generator and template files are 140 kilobytes each, and the sample clinic model is nearly 210 kilobytes. Figure 2 provides a system view of the software.

The clinic template contains all of the worksheets and VBA macros that are needed for a planning model. These worksheets contain text, formatted cells, navigation buttons, and many of the equations needed. To create the planning model, VBA macros accept user input, open the template, copy and paste cells from the template as needed, write formulas directly into the worksheets, and save this modified workbook as the planning model.

The clinic planning process involves three steps. First, the planner gathers the information that will be used and determines the flow of residents from one station to another within the clinic. The user guide provides blank forms to help with this task. Second, the user opens the clinic generator workbook; this starts a VBA macro that asks the user for information about the clinic. The macro then modifies the clinic template workbook to create and save a new workbook, which becomes the user's clinic planning model. Third, the user, working directly in the new workbook, enters additional information, modifies the clinic specifications, and views the performance estimates.

The documentation includes the user's guide and the sample clinic model. The user's guide defines

important terms related to the queueing model, describes how to prepare the information that the model needs, shows the model-creation process (with an example), describes each sheet in the clinic-planning model workbook, and includes the routing worksheets. The sample clinic-model workbook is a completed clinic planning model; it corresponds to the example in the user's guide. Although it allows changes to some parameters, it does not allow the user to change the number of stations (or to add or remove batch-processing stations) from any existing clinic planning model.

Spreadsheet Elements

The software automatically generates a spreadsheet from a minimal set of user inputs. Thus, planners do not have to create spreadsheets from scratch or understand the mathematics of queueing networks; yet, they generate a spreadsheet capacity planning and queueing network model that reflects the design they want to use. The software provides useful data that include processing-time distributions for different types of workstations, but it allows the user to make modifications as necessary.

The planning-model workbook consists of five worksheets; each has an assigned color; blank cells and cells with headers are filled with that color. Cells in which the user may enter data and cells that display calculated results are shown with a white background. To move from one sheet to another, the user clicks on color-coded navigation buttons along the top of each worksheet (each button runs a VBA macro that brings the corresponding sheet to the front). The "main" worksheet shows user inputs in a column on the left and calculated results in a column on the right. The "parameters" worksheet allows the user to change some general parameters about the clinic and parameters for each station, including the processing-time distribution. The "routing table" worksheet has tables for specifying the routing probabilities and distances between stations. The "staffing" worksheet has a list of blanks for entering position titles and the number of staff members in each position. The "report" worksheet has a less colorful, document-like layout to allow the user to print the results. It includes two bar charts showing station utilization and queueing.

To simplify the user interface, the clinic planning model does not display navigation elements (e.g., sheet tabs) and hides the calculation worksheet. However, a user can change these options and unhide the calculation worksheet, if desired. Thus, a user can see and change any of the spreadsheet details. The resulting spreadsheets follow good spreadsheet design practices (Powell and Baker 2004). They are modular and use different worksheets for different data types. A modular design is critical to writing software that must automatically build spreadsheets from a template.

The key user inputs (i.e., the number of patients to be treated and the number of staff members at each station) are located near each other on the same worksheet and are easy to change. The key performance measures are displayed on the same page so that users can immediately see the impact of changing input data. The calculations are on another worksheet, which is hidden.

Spreadsheet Dissemination

Prior to disseminating the software, we met with many public health emergency preparedness planners to describe the software and help them to start using it. In February 2006, 32 planners participated in training sessions at a NACCHO conference. These participants had the opportunity to use the software on laptop computers that we set up in the meeting room; our team helped them build models. We also ran separate workshops for planners from two counties in Maryland and one in Minnesota. In addition, the New York State Department of Health used the software to plan 59 POD exercises.

As of May 2007, our list of registered users included 65 public health emergency preparedness planners from 25 states. Between June 2005 and May 2007, the Montgomery County APC received 11 requests for information about the software. In April 2006, 135 planners viewed a Web-based seminar about the software.

Although we require no payment or registration from users when they download our software, we do ask them to notify us so that we can inform them when updates become available. The University of Maryland retains ownership of the copyright. Based

on the feedback we have received from users, we are continuing to create updated versions of the software and post them on our website. However, existing clinic planning models continue to work. Not charging for the software removes a large obstacle to dissemination. The APC pays for the software and wishes to see it distributed to the widest possible audience. Moreover, this approach best fits our institution's vision, which states that the University of Maryland will make "the results of its research available for the use and benefit of the State of Maryland and its people" (University of Maryland 2000).

Benefits of Spreadsheets

The spreadsheet-software approach has many benefits. The clinic planning models are portable and self-contained and require only Microsoft Excel. Because most public health emergency preparedness planners already use Excel, they do not have to buy new software. Moreover, the spreadsheet concept is so familiar that users can learn the software quickly

Spreadsheets are suitable for rapid development; exploiting the existing infrastructure of Microsoft Excel and VBA greatly reduces the software development effort. It also provides a rapid prototyping capability. We can rapidly modify the model to evaluate potential improvements that users want; after identifying a feasible, desirable change, we can modify the clinic template and the VBA macros so that all future clinic planning models incorporate that change. Developing the VBA macros needed to generate the models from user inputs did require significant effort; however, this approach increased the flexibility tremendously. A set of predefined spreadsheet models would have been insufficient. Unlike discrete-event simulation, which requires many long replications to estimate queue lengths and waiting times, a queueing network model implemented as a spreadsheet can calculate performance estimates immediately whenever the user changes a parameter.

We wrote and published a report that presented the mathematical models (Aaby et al. 2006b); however, this was not an acceptable alternative to creating a computer-based tool. We realized that we could not expect public health professionals to take the time to understand the mathematical models in sufficient

Distribution option	Ease of use	Variety	Run time	Need to buy software	Development effort
Predefined spreadsheets	Very easy	Very low	Very quick	No	Little
Software that builds spreadsheets	**Easy**	**High**	**Very quick**	**No**	**Moderate**
Predefined simulation models	Fair	Very low	Slow	Yes	Little
Software that builds simulation models	Easy	High	Slow	Yes	Moderate
New software	Easy	High	Very quick	No	Large
Mathematical formulas	Difficult	High	Very quick	No	None

Table 1: Our qualitative evaluation of distribution options showed software that builds spreadsheets (boldface in the table) to be our best option because it would be easy to use, be able to model many different types of clinics, run very quickly, require the purchase of no special software, and need only a moderate amount of development effort. Variety refers to the ability to model a wide range of clinic designs.

detail to implement them. In addition, this would have increased the probability of user errors. Table 1 shows our evaluation of the available distribution options for the models.

Spreadsheet Development Approaches

Developing software for distributing spreadsheets to a large set of diverse users required a unique approach that is based on, but substantially different from, end-user modeling and typical spreadsheet applications.

End-user modeling, a process in which decision makers build and run their own models, has four key characteristics (Powell 1997):

(1) The decision maker builds the model.

(2) The approach is quantitative but not analytical.

(3) The style is quick and informal.

(4) The purpose is to gain insight into a decision or problem.

The three primary steps to building good spreadsheets for end-user modeling are planning, programming, and crafting the user interface (Powell and Baker 2004). Similarly, Grossman (1999) suggests that end-user modelers should follow these steps:

(1) Turn off their computers.

(2) On paper, write down what the spreadsheet will look like.

(3) Execute the paper spreadsheet by hand.

(4) Iterate using Step 3.

(5) Turn on their computers and begin to program.

Edwards et al. (2000) provide guidelines and suggestions for using OR specialists in developing spreadsheets. Thiriez (2004) provides several examples of professional spreadsheets that he created for clients. Based on his experience, he praises the spreadsheet's ease of use, transparency, need for no additional software, and reduction of development effort.

There are significant differences between these processes and the development of our Clinic Planning Model Generator. First and foremost, the Clinic Planning Model Generator is not end-user modeling. We were acting as analysts (i.e., constructing models for a client); we were not acting as a decision maker and building a spreadsheet for our own use. Because we wanted to provide more flexibility, the typical spreadsheet application approach was insufficient; therefore, we decided to create a spreadsheet application that, based on user input, automatically modifies a spreadsheet template to generate a custom clinic planning model. Thus, the software approach is similar to source code generation.

From the user's perspective, the Clinic Planning Model Generator resembles a highly structured end-user modeling process as follows:

(1) The user plans the model by collecting data and using a predetermined form to document the flow of residents through the clinic.

(2) The user does not have to program the model but merely enters data in a structured way.

(3) The user does not have to craft the user interface; the model creates it automatically.

(4) The user can modify spreadsheet values, formulas, and source code.

Challenges

The biggest challenge to our spreadsheet modeling approach has been finding a good compromise between flexibility and structure. We need flexibility because planners want to evaluate a wide variety of designs. We need structure to make programming feasible and to reduce the user learning time.

One of our key reasons for creating a new modeling tool was that existing queueing network analyzers use language that is unfamiliar to public health professionals. Therefore, we defined queueing terms in language that they could understand; our software also uses the correct emergency preparedness terms. Unfortunately, these terms tend to change over time. For example, the term "points of dispensing" is now preferred over "mass vaccination clinic." Changing terms requires us to update presentations, documentation, and reports accordingly.

From a scientific point of view, the use of approximations means that the spreadsheet provides only estimates of performance. Despite the large body of literature on queueing networks, we had to develop new approximations that are relevant to this domain. We have characterized the accuracy of our estimates and are continuing to work on better approximations (Treadwell and Herrmann 2005, Pilehvar and Herrmann 2006, Pilehvar 2007). In this situation, a useful, reasonable approximation is preferable to an exact procedure that is difficult to apply in practice.

Conclusions

Developing software to create spreadsheets for a large set of diverse users has been part of an exciting process to use OR to improve planning for bioterrorism attacks, pandemic influenza, and other health-related emergencies. The result is a two-stage process. In the first stage, we developed the software, which we implemented as VBA macros within a spreadsheet. In the second stage, the user runs the VBA macros to create a customized spreadsheet.

This experience has provided some lessons for using spreadsheets. From the user's perspective, spreadsheets eliminate the requirement to purchase software, reduce the amount of training, and provide flexibility; users can easily modify the models to meet their needs. To the application developer, they exploit an existing infrastructure that reduces the development effort and increases the likelihood that users will adopt the application. To the OR analyst, they provide a reliable way to make mathematical models available and reduce errors because the users only need to enter key values; they do not need to understand or program the equations.

The process is significantly different from end-user modeling and from developing a typical spreadsheet application for a single client. It has relied on the

ability to conduct rapid prototyping and the cooperation of motivated users.

We are continuing to develop the software based on feedback from the public health professionals who are using it. Because they are not operating PODs, further validation will come from exercises and from similar clinics set up to limit the spread of more common diseases (such as influenza).

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Patrick M. Libbey, Executive Director, NACCHO, 1100 17th Street, NW, Washington, D.C. 20036, writes: "I am writing about the software developed for the Montgomery County, Maryland, Advanced Practice Center (APC) for Public Health Preparedness by Jeffrey W. Herrmann, Department of Mechanical Engineering and Institute for Systems Research, University of Maryland, College Park. The Centers for Disease Control and Prevention (CDC) funds the APC program. The National Association of County and City Health Officials (NACCHO) administers the program and maintains an online clearinghouse of APC preparedness tools for local public health agencies.

"The Clinic Planning Model Generator software and the associated spreadsheets are designed to help public health officials prepare for a major bioterrorism event or other public health hazard where it would be necessary to give medication to or vaccinate a large number of residents in a short period of time. In such a situation, time would be of the essence; staff and available sites would be in short supply. Moving people through lines in the most efficient way would

be crucial. Having enough staff at each station—but not more than needed—is important for using limited staff. The use of software to generate useful spreadsheets automatically is an innovative and effective approach.

"Through the Montgomery County, Maryland, APC, the software that Dr. Herrmann's team has developed is being made available to public health officials around the country. In addition, Dr. Herrmann has participated in training sessions at the NACCHO APC Training Conference in February 2006.

"When staff is limited and there is a deadline by which medication must be administered in order to be effective, a county's ability to serve its residents in a timely manner is extremely important. The clinic planning models have helped counties across the United States create better plans that assign the correct number of staff to the proper locations. This outstanding work enhances the emergency preparedness of the entire country. We appreciate Dr. Herrmann's efforts to make these models available to the widest possible number of public health officials.

"The work of Dr. Herrmann and the models developed provide critical planning and assessment tools to Public Health Departments in evaluating their capabilities to meet their mandates during public health emergencies."