MASTER'S THESIS

Queueing Models and Assessment Tools for Improving Mass Dispensing and Vaccination Clinic Planning

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ABSTRACT

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To react to an outbreak of a contagious disease that requires medication or vaccination, county health departments must set up and operate mass dispensing and vaccination centers, commonly known as points of dispensing (PODs), to treat residents who may be affected. Carefully planning these PODs before an event occurs is a difficult and important job. Simulation models can provide an accurate representation of resident flow through PODs, but are not convenient for public health professionals to access. Queueing theory provides a multitude of analytical models appropriate for various situations – so many models that it is often difficult to discern which model is correct for a particular circumstance. There are also some situations for which no models are available, particularly those involving batching and multiple servers. A complete set has been gathered of those models that are the most generalized, and hence useful for the widest range of applications. Where no

appropriate model was available, modifications to the existing equations are proposed and tested.

To implement this general queueing framework, software has been developed which can quickly generate planning models using steady-state queueing network approximations; these models use commonly available spreadsheet software to maximize accessibility for public health emergency planners. The planning models are validated against models created in several queueing software packages, along with simulation models automatically generated from the planning models.

The number of stations and staff within a POD are not the only concerns that a public health emergency preparedness and response plan must address. A plan assessment tool is proposed, which can help planners ensure that their POD plans include all relevant information. A layout assessment tool is also developed, which endeavors to give planners suggestions on how to design PODs for maximum efficiency.

QUEUEING MODELS AND ASSESSMENT TOOLS FOR IMPROVING MASS DISPENSING AND VACCINATION CLINIC PLANNING.

By

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Chapter 1: Introduction

Since the terrorist attacks of September 11, 2001, state and local public health agencies have focused their preparedness planning efforts around the possible threat of a biological terrorist attack, involving an agent such as anthrax or smallpox. They have developed plans for mass dispensing and vaccination centers (DVCs), also known as points of dispensing (PODs) in order to treat a potentially large number of residents in a short time. Unfortunately, it is difficult for public health agencies to test their plans using various scenarios due to lack of resources and time to conduct exercises. For this reason, local public health agencies need tools and resources to evaluate and adapt their POD plans in a timely and succinct manner. To assist in this effort, the Centers for Disease Control and Prevention (CDC) and the National Association of County and City Health Officials (NACCHO) established eight Advanced Practice Centers (APCs), of which Montgomery County, Maryland is one, to develop cutting-edge tools and resources for local public health agencies nationwide to prepare for, respond to, and recover from major emergencies.

1.1 Motivation

In engineering, performing experiments on a real system is often infeasible – for instance, it may be expensive to take a manufacturing system offline to investigate different setup options; in other cases, the system simply does not exist yet in a physical form, and the purpose of running the desired experiments is to choose what form it should take. In these and other cases, a common strategy is to create a model of the system. If the model has been verified (shown to work) and validated (shown to represent the real-world system to the desired degree of accuracy) then it can be accepted as a valid substitute for the real system. When experiments are performed on the model, their results will provide intuition on how the real system will respond to a given change.

The challenges faced by public health officials are very similar to these engineering situations. Public health officials are trying to write their plans to provide the best response possible if activated, but when it comes to testing the plans, resources are limited and opportunities rare. Even when a simulated event is held to exercise a plan, there is only so much realism that can be achieved; exercises are generally run for a few hours to a day, while in an actual event, PODs would be up and running for as long as necessary to treat the affected population.

Using appropriately accurate models to aid in POD design gives emergency planners a huge advantage in their work. They can not only estimate the appropriate number of workers they need to staff a POD for a given situation, but also assess the effects of adding or removing staff members at different stations. Planners can also evaluate various strategies of managing resident arrivals, along with the impact of including various "optional" stations. In short, models can liberate planners from blind obedience to guidelines that may or may not fit their situation, or from using guesswork with little basis in reality. Instead, they can make educated decisions, based on a model that is customized to reflect the particular circumstances of their own department and of the contingency that is being planned for.

1.2 Objectives of the research

To date, extensive effort has gone into creating newer and better equations describing, exactly or approximately, various parts of queueing systems. For a given type of service process, one can select among a multitude of equations approximating such measures as customer waiting time and the variability of arrival and departure processes. However, little progress has been made in bringing together the various models that have been proposed.

The goal of this research is to compare analytical models of queueing processes to discrete-event simulations in order to determine which models are the most accurate for use with a general set of inputs. By combining them into a unified framework, and modifying them where appropriate, they are made more readily accessible for timely application. The framework is implemented in software targeting public health officials and emergency planners; however, the structure behind this can be easily adapted to any application where a network of stations must be configured in order to handle a certain amount of throughput. This model will be constructed and run using readily available spreadsheet software.

1.3 Outline of the thesis

The thesis is organized as follows: Chapter 2 provides background about emergency planning, POD design software, and the modeling techniques used in this research. The full-scale smallpox simulation exercise that inspired the original work is described, along with the basics of simulation modeling and queueing network theory. Chapter 3 describes the approach used for building the models. Details are given about the time studies that were performed to obtain real-world data. The construction of simulation and queueing models is also discussed. Chapter 4 discusses experiments that were performed in order to determine the necessary adjustments to extend the use of existing analytical queueing models. Models of the three PODs where time studies were performed are discussed as examples; each POD is described in detail, and results produced by the analytical models are compared to results of the equivalent simulation models. Chapter 5 describes software that was written which takes the spreadsheet containing a POD model and uses it to replicate that POD in a simulation model. Chapter 6 presents assessment tools that were created for evaluating POD plans, as well as the layouts of stations within a POD facility. Chapter 7 concludes the thesis and recommends areas for future investigation.

Chapter 2: Background

The field of emergency planning is one in which new challenges are constantly appearing; since the terrorist attacks of September and October 2001, the scope and urgency of emergency planners' duties has increased significantly. Fortunately, guidelines do exist to aid planners in their work, along with several pieces of software. However, there is room for improvement in the currently available software tools, particularly with regard to their ability to adapt their models to a particular situation.

In order to test their plans and give their personnel training under real working conditions, local governments sometimes run full-scale disaster simulations. One such exercise is detailed below, which was run by Montgomery County, Maryland in 2004; the performance measures recorded there were used to build a computer simulation model. An operations research discipline called queueing theory is also useful for modeling the performance of PODs, and is discussed below in some detail. Another relevant area of study is queueing methods.

2.1 Emergency planning

According to the "Community-Based Mass Prophylaxis" guide, there are five main components to outbreak response: surveillance, supply and stockpiling, distribution, dispensing, and follow-up (AHRQ, 2004). When surveillance teams have identified a disease outbreak, medication from the Strategic National Stockpile (SNS) will be distributed at the federal and state levels. Receiving and dispensing this medication is the responsibility of local public health authorities, and plans generally take one of two forms: "push" or "pull". In a push approach, medication is delivered directly to the residents in a community, for instance by postal workers (USPS, 2004). Conversely, a pull approach requires individual residents, or a representative for multiple residents, to come to where the medication is (AHRQ, 2004). This pull approach to vaccination and dispensing will be the focus of the thesis.

The Agency for Healthcare Research and Quality (AHRQ) proposes that any plan involving the use of PODs must include the command, logistical, and operational requirements for both a single POD and a scalable operation involving multiple PODs, in order to be useful for various scenarios. Factors that should be considered in planning, illustrated in Figure 2.1 include who must be involved in the response, what resources are required, where the PODs will be sited, when they will be opened, and how they will be run. The last item is of particular interest; it involves such

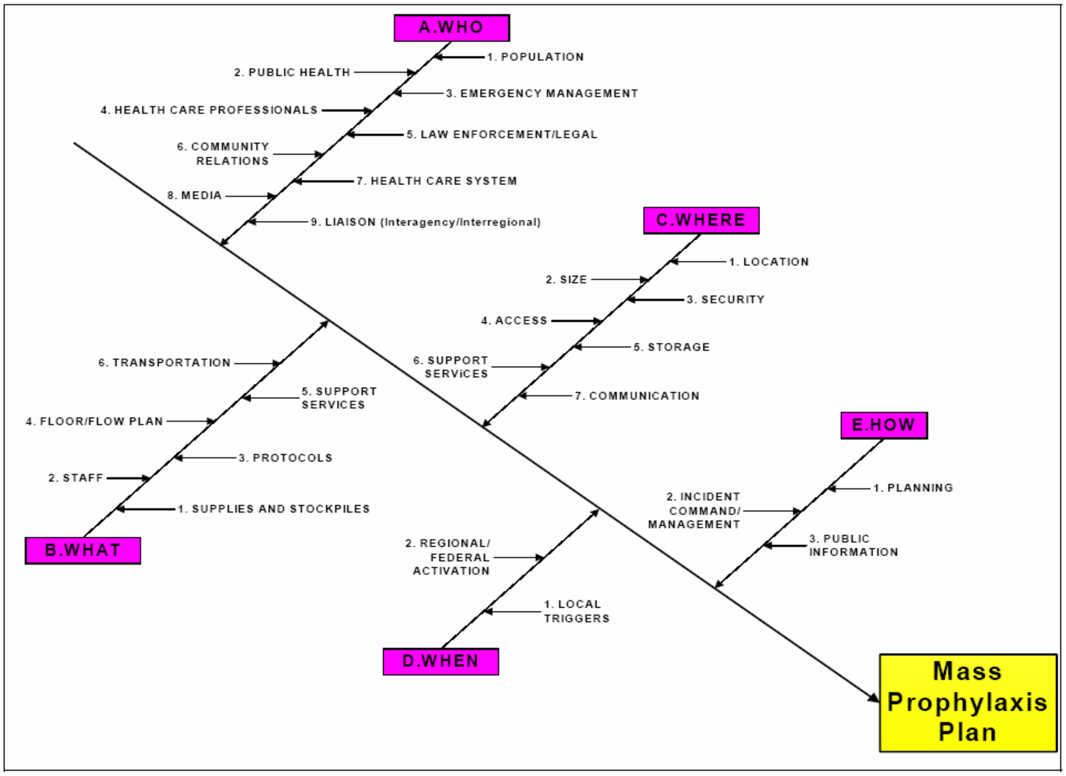

Figure 2.1. Elements of a local mass prophylaxis plan (AHRQ, 2004: p.5).

issues as what core stations and support functions will be part of the POD, and their physical arrangement. POD design is one area of POD planning where software tools can be especially helpful to public health emergency planners (referred to "planners" hereafter for the sake of brevity) who have limited experience with similar situations in the real world.

2.2 POD design software

Several tools exist to aid emergency planners in creating POD designs. The best known of these is the Bioterrorism and Epidemic Outbreak Response Model (BERM), funded by AHRQ and developed by researchers at Weill Medical College of Cornell University (Hupert, 2003). 3M has also developed a commercial tool, but the tool focuses on forecasting a POD's supply needs for stockpiling purposes, and is not reviewed here. The CDC offers guidelines for planning a smallpox clinic; these guidelines include sample staffing levels for vaccinating 1 million people in 10 days, but do not consider other possible scenarios. The CDC has also developed a software package called Maxi-Vac, which provides data for a limited number of smallpox-related scenarios.

2.2.1 BERM

BERM Version 1.1 (Hupert, 2003), released in 2003, presents two possible scenarios: a communicable disease, such as smallpox, and a non-communicable disease, such as anthrax. The user selects various high-level inputs to customize the setup to meet local needs, and the model recommends the number of PODs to open, the number of staff per POD, and how many of each type of support staff per POD. The model also allows the user to set limits on the number of staff who can work in each POD at any given time, or on the total number of staff available. The software provides flow models to help the user understand the two scenarios, and a sample physical layout suggesting station locations and queueing arrangements. The authors provide a customizable staff model as a separate tool, which allows more user inputs but offers little guidance. AHRQ released Version 2 of the model (see Figure 2.2) in 2004; it provides a slightly more navigable user interface, but does not significantly

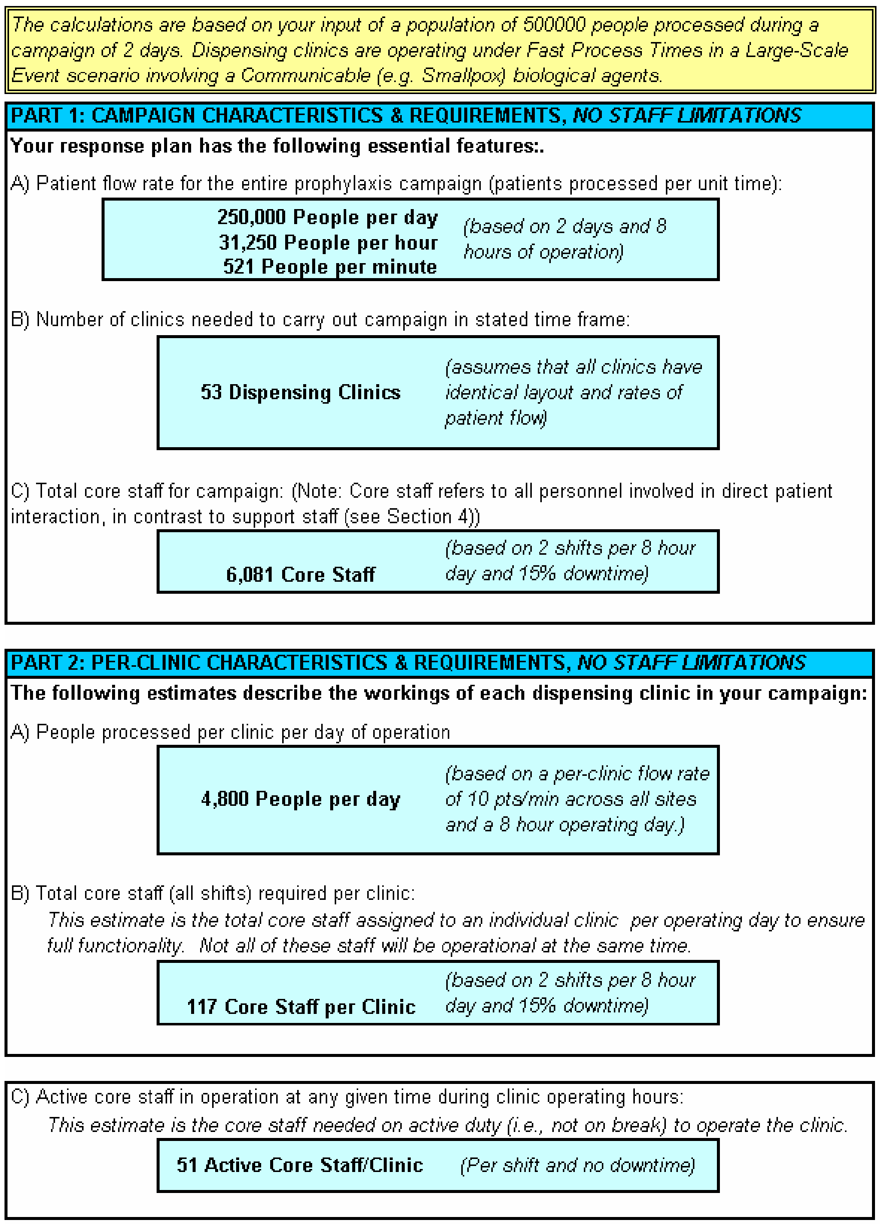

Figure 2.2. Overall Model Outputs from BERM 2.0 (AHRQ, 2004).

alter the model's functionality.

2.2.2 Maxi-Vac

The CDC initially released its Maxi-Vac software in 2002, and has since updated it to increase the accuracy of the included data. The tool's objective is to help state and local planners choose how to distribute available personnel among the requisite stations of a smallpox vaccination clinic. The tool does not perform dynamic calculations; instead, it relies on a database of results from experiments run in Rockwell Software's Arena 5.0 ®. This significantly limits the tool's usefulness, as users must make their choices from among a limited set of options. For instance, the number of physicians available per shift must be one, three, five, or nine, while the number of nurses is limited to 15, 30, or 45 (Figure 2.3). After entering selections for available staff of various types, and choosing briefing room capacity (30 or 75 residents), results are presented to the user. These include the number of residents that the clinic staff can treat in a 24-hour period and the optimum distribution of staff among stations, as determined for that particular scenario by the OptQuest add-in for Arena. Other results presented are staff utilization, the average time families spend at each station, and the impact that adding or removing one staff member has on the throughput of each station. While the software can be useful for gaining some insight into the relative capacity of individual POD designs, it offers little help with planning for the needs of an entire population. CDC released an "alternative" version of the Maxi-Vac software in 2005, which allows the user slightly more flexibility; for instance, one can remove certain stations from the POD flow, and adjust the percentages used to route families to optional stations. This version also employs radically different values for service times at several of the stations.

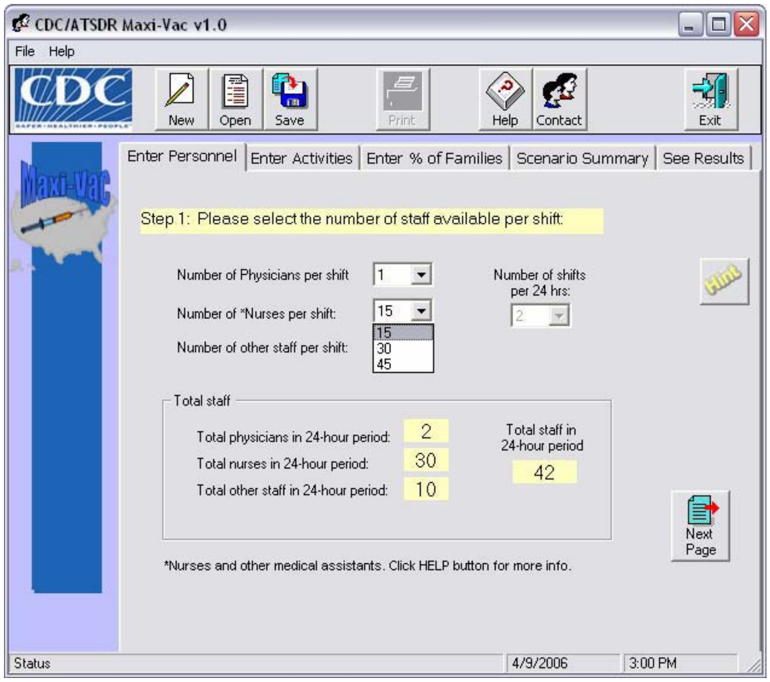

Figure 2.3. Personnel entry screen of Maxi-Vac software (CDC, 2003).

2.3 Dagwood exercise

In order to simulate the mass vaccination procedures that planners had developed, Montgomery County conducted a full-scale exercise, code-named Operation Dagwood, on June 21, 2004. In this exercise, 152 county employees served as professional, command, and administrative personnel. Approximately 530 volunteers from the local workforce and community participated in the exercise as residents during a period that lasted two-and-a-half hours. County workers, especially staff from Public Health Services, were encouraged to participate with their families. A number brought elderly family members and children, and the volunteers included individuals with physical disabilities.

Researchers and student volunteers from the University of Maryland conducted a time study to collect data on POD performance during the exercise. The average arrival rate was 213 residents per hour. Analysis of the data yielded estimates of how long each resident spent at each station, the total time spent in the POD, and the average time that a staff member spent serving a resident at each station.

2.4 Simulation models

Discrete event simulation software allows the user to create a model of the real world where entities (e.g. residents) travel through a network of service nodes. Arrival rates and service times for each entity are random numbers fit to a distribution determined by time studies of the actual system. Once the user has created, validated and verified a model, they can adjust the system and analyze the response. This allows the user to determine how a proposed change will affect a system without investing the time and money that would be required to make the change in the real world.

During the summer of 2004, Daniel T. Cook, a student in the Research Experience for Undergraduates program, created simulation models of the Montgomery County exercise using Rockwell Software's Arena® (Aaby et al., 2006a). For validation purposes, the initial model was meant to simulate the exercise as it occurred. Residents arrived in batches that corresponded to the actual bus arrivals. The model represented each resident as an entity that progressed through different queues and processes. It included animation for visualizing the movement of residents through the POD. Once the models had been validated, they were adjusted in order to analyze the effects of various proposed policies governing POD operations and staffing. The proposals under investigation included changing the sizing and arrival times of buses carrying residents, changing classroom sizes or replacing classrooms with an auditorium for showing an educational video, and adjusting the number of staff at various stations.

2.5 Queueing network approximation models

The discipline of queueing theory deals with the use of mathematical models to represent the behavior of customers competing for access to a constrained resource. Operations research is comparatively new as a formal discipline, but researchers have studied queueing theory for nearly 100 years. There are several relevant aspects of queueing theory: approximations have been developed to estimate waiting times, and variations exist to handle situations such as batch arrivals and processing. Multiple queueing systems may also be strung together to create a queueing network.

2.5.1 Historical perspective

Queueing theory was first developed by A.K. Erlang, who used probability techniques to determine the required number of telephone lines at the Danish Telephone Company in 1909 (Gross and Harris, 1974). Communications networks have remained one of the most prominent applications of queueing, but since at least 1949, engineers have also used Erlang's theories to predict the performance of production facilities; in 1950, Ashcroft discussed the operation of automatic machine tools demanding attention from an operator, and others discussed similar topics even earlier (Bernstein, 1941; Field, 1946). Kendall created a standard notation for various types of queues in 1953; the notation takes the form of A/B/C, where A refers to the arrival process, B to the service process, and C to the number of servers. The arrival and service processes can be exponential (referred to as Markovian in recognition of Markov's research on stochastic processes, and denoted by M), deterministic (D), Erlang (E_k), or general (G) (Kendall, 1953).

In 1957, Jackson defined what we now know as a Jackson network: a series of nodes with probabilities governing travel between the nodes. Customers arrive from outside the system to any of the nodes (making this an 'open' network), and leave from any node where the total probability of travel to other nodes is less than 100%. Jackson concluded that, knowing arrival rates, service rates, and number of servers for each station, he could treat each of these nodes as an independent, elementary system (Jackson, 1957). Gordon and Newell also considered closed networks, with a certain number of customers trapped within the system (Kleinrock, 1975); however, this case is not useful for the models considered here.

2.5.2 Waiting times

In its simplest form, queueing theory can be used to describe the time a customer spends waiting for a single server to become available, based on the mean time that that server takes to process each customer (service time, or τ), and the rate at which customers arrive (arrival rate, or λ). This simple model assumes that both interarrival times and service times are distributed exponentially (in other words, with standard deviation equal to the mean), and that the number of servers (m) is equal to one; in Kendall's notation, this type of queue is referred to as M/M/1. An important characteristic of the station is the proportion of time during which servers are busy; this is referred to as utilization or traffic intensity; it is defined as $\rho=\lambda\tau/m$. The expected queueing time (*CTq*, for cycle time in queue) in any system is proportional to the mean service time τ; in an M/M/1 system, the coefficient is based simply on the utilization, as shown below.

$$CT_{\mathrm{q}} = \frac{\rho}{1-\rho}\tau \tag{2.1}$$

In order to generalize this formula for use with non-Markovian arrival and service processes, variance terms for each are added. The variance is scaled against the square of the mean to make it dimensionless; this number is called the squared coefficient of variance (SCV), and is represented by c_a^2 for the arrival process and c_e^2 for the service process. This turns the exact equation into an approximation, but provides a good estimate unless c_a^2 and c_e^2 are much larger than one, or ρ is greater than 0.95 or less than 0.1 (Hopp and Spearman, 2001). It can readily be seen that for Markovian processes, where c_a^2 and c_e^2 are equal to one, this equation simplifies to (2.1). The G/G/1 approximation for queueing time is:

$$CT_{\mathrm{q}} = \left(\frac{c_a^2 + c_e^2}{2}\right)\frac{\rho}{1-\rho}\tau \tag{2.2}$$

One situation that these equations do not fully represent is that of multiple servers working in parallel to process several customers at one time. Sakasegawa (1977) proposed an approximation for this queueing time, with *m* representing the number of servers, given in (2.3); the main difference is in the power to which the utilization is raised, along with the scaling of the mean service time τ for multiple servers. When $m = 1$, this equation reduces to the G/G/1 approximation in (2.2).

$$CT_q = \left(\frac{c_a^2 + c_e^2}{2}\right)\frac{\rho^{\sqrt{2(m+1)}-1}}{(1-\rho)}\frac{\tau}{m} \tag{2.3}$$

2.5.3 Batch processes and arrivals

In some systems, customers are handled in groups called batches; two common uses for batches are in processes that have long service times and lots of physical space (e.g. curing parts in an oven) and for transportation between stations. The number of customers in a batch is represented by k. When customers arrive at a batch process, they must first wait while the other customers in the batch arrive, then wait as a batch for the server to become available. Hopp and Spearman (2001) refer to this first delay as wait-to-batch time (WTBT), and define it as:

$$WTBT = \frac{k-1}{2\lambda} \tag{2.4}$$

After the batch is formed, queueing can be approximated using the formulas previously discussed, substituting parameters pertaining to the batch for the individual parameters. When a process must wait for multiple individual customers, the important arrivals are the first and the last ones; this means that the SCV of the batch is dramatically lowered, a phenomenon known as variability pooling. The SCV as the batches are formed and arrive at the process is obtained by dividing the individual arrival SCV (c_a^2) by k (Hopp and Spearman, 2001).

When customers arrive at a station in batches for individual processing, there are two ways of handling them. The first is to treat them as individuals arriving in a process with an extremely high SCV; the arrival variability of individuals out of a batch is given below (Curry, 2002), where the SCV process of a batch is denoted by $c_{a,b}^2$.

$$c_a^2 = kc_{a,b}^2 + k - 1 \tag{2.5}$$

The second way of dealing with "unbatching" is to find the time that the batch spends in queue with other batches, then add the time that individuals spend waiting once the batch they arrived in is “opened”, referred to as wait-in-batch time (WIBT) (Hopp and Spearman, 2001).

$$CT_q = \left(\frac{\frac{c_a^2}{k} + \frac{c_e^2}{k}}{2} \right) \frac{\rho}{(1-\rho)} k\tau \qquad (2.6)$$

$$WIBT = \frac{(k-1)}{2}\tau \qquad (2.7)$$

Curry and Deuermeyer (2002) compared these two unbatching strategies and found that the approach suggested by Hopp and Spearman gave results that were significantly better when compared to a simulation. However, neither Hopp and Spearman nor Curry and Deuermeyer considered the case of unbatching at a station with multiple servers.

2.5.4 Queueing networks

The queueing models discussed above all apply to the modeling of a single process. Many applications deal with networks of stations with queues, where customers pass from one station to another in a certain sequence or set of possible sequences. In this situation, the departure process from each station becomes important. As long as the station is stable (that is, as long as the mean service time is less than the mean interarrival time), the mean rate of departure is equal to the mean rate of arrival. The actual pattern of departures will be different from the arrivals, however, and this is described by calculating the SCV of the departure process (c_d^2). Whitt (1983) calculates the departure process SCV as a function of c_a^2, c_e^2, ρ, and m:

$$c_d^2 = 1 + \left(1-\rho^2\right)\left(c_a^2 - 1\right) + \frac{\rho^2}{\sqrt{m}}\left(c_e^2 - 1\right) \tag{2.8}$$

When customers arrive from different stations, the SCV for the departure process at each "feeding" station contributes to the SCV of the arrival process at the "receiving" station. The routing probabilities between stations are defined by q_{ij}, which represents the probability that a customer leaving station *i* will arrive at station *j*. Routings are assumed to be Markovian, meaning that they are independent of the past and present states of the network (Whitt, 1983). An approximation for the SCV of the arrival process experienced at station *j* is shown in (2.9) (Herrmann and Chincholkar, 2001); this equation is achieved by combining Whitt's approximations for splitting and superposition (1983).

$$c_{aj}^2 = \sum_{i=1}^{j-1}\left(\left(c_{di}^2 - 1\right)\cdot q_{ij} + 1\right)\cdot\frac{\lambda_i \cdot q_{ij}}{\lambda_j} \tag{2.9}$$

Nearly a century of research in queueing theory has produced a myriad of analytical models covering a broad spectrum of circumstances; however, models in some areas need to be created or refined. For instance, extensive effort has gone into developing models to optimize batch sizes, but no equations appear to exist for estimating the performance of queueing networks that include batch processes at some or all of the stations. Further investigation is also needed into situations combining several non-standard characteristics, like stations with batch arrivals and multiple servers.

2.6 Queueing methods

The study of queues is not limited to creating mathematical models of customers waiting for servers. Another particularly practical aspect of queueing is the physical arrangement of queues and servers. There are many seemingly minor details in the planning of a queue which can have a significant effect on the customer experience; I will introduce a few of the important concepts and define several terms which will come up in later discussions of POD design. The discussion below is a summary of some relevant information from Hall (1991).

In any system where customers visit stationary servers, the system will fall into one of two categories: turn-back or flow-through. Turn-back systems place all servers in a line behind a counter; customers approach the counter, receive service, and then turn away from the counter to leave. In a flow-through system, customers enter a lane to receive service, as shown in Figure 2.4. When service is finished, the customer continues moving in the same direction as when they entered. Turn-back systems are effective when workers need access to shared equipment, for example in a post office. Flow-through systems are useful when servers only require a small station, like that of a supermarket cashier.

Figure 2.5 illustrates several factors that affect server visibility to customers. Separation angle (θ) is the angle from the leftmost server to the rightmost server; the customer has to scan this entire arc in order to be aware when a server becomes free. Separation angles below 30° can be monitored with peripheral vision, while angles from 30-80° can be monitored through eye movements alone. Angles beyond 80° require head movement, increasing resident response time. Sight angle (α) is the angle between the server line (defined by the front edge of the service counter) and the customer's line of sight. As the sight angle narrows (for instance, when the length of a service counter is extended), it becomes harder for customers to spot available servers; 90° is the ideal sight angle, which could be obtained by placing servers in an arc centered on the head of the line.

Both sight angle and separation angle are affected by the distance between the head of the line and the service line, known as the setback. It will become quickly obvious that as setback increases, the sight angle approaches perpendicular and the separation angle narrows. However, the further away the customer is from the servers, the more time is wasted as he or she walks towards them after they become available. One technique that Hall (1991) does not discuss to reduce this travel time is the use of staging; this refers to placing customers in an "on deck" position a few feet away from each server. When the server becomes available, the customer only needs to take a few steps to reach the service position; while the server processes this customer, another customer advances to the staging line. Customs lines in airports commonly employ this practice.

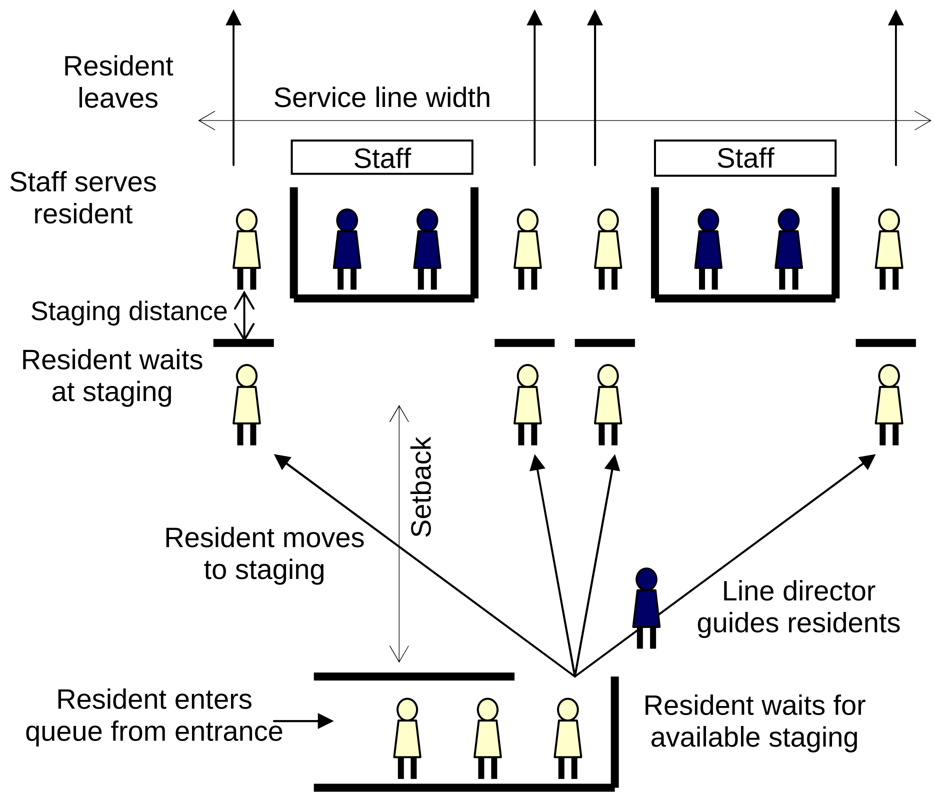

Figure 2.4. Illustration of queueing practices.

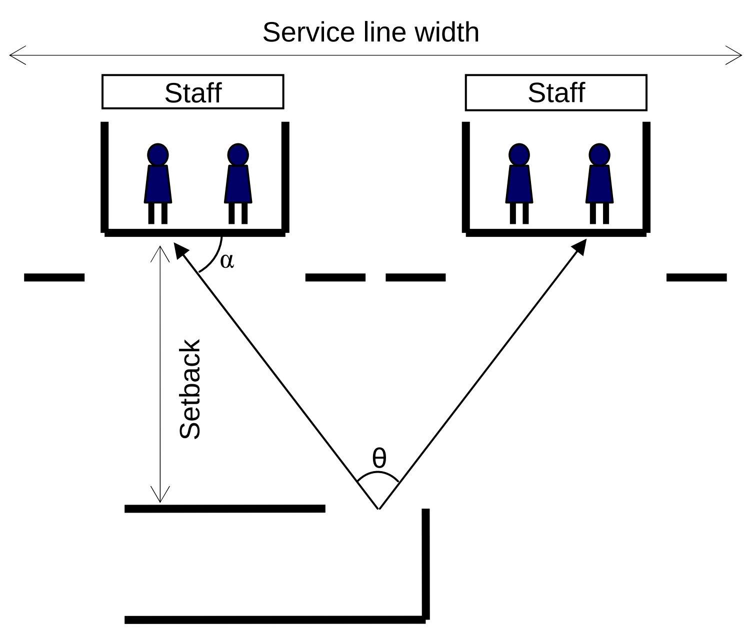

Figure 2.5. Illustration of queueing terms.

Chapter 3: Approach

I set about the process of building POD models and refining their construction in a sequential manner. First, I recorded various performance measures at several full-scale exercises that various nearby jurisdictions were running. I used the performance data to create simulation models; I then created corresponding steady-state analytical models and compared them to the simulation results for validation.

3.1 Data gathering (time studies)

Time studies were performed at several POD exercises in 2004 and 2005 in order to obtain data for modeling the PODs. Data gathered for a previous project at Montgomery County, Maryland's Dagwood exercise, held June 21, 2004, was the basis for the start of the project. Time studies were also performed at Burlington County, New Jersey's TOPOFF 3 exercise on April 7, 2005, and at a Montgomery County, Maryland annual flu clinic, held November 2, 2005. The data obtained in these time studies was used to validate models of each POD design.

3.1.1 Dagwood

On June 21, 2004, Montgomery County, Maryland held its Dagwood exercise. As residents arrived at the POD, they were given time sheets; these were stamped with the arrival time, and then stamped as the resident left each station; this allowed the cycle time for the stations to be calculated. Video data was also taken of various stations in order to determine service time distributions. Walking speeds and distances between stations were measured in order to calculate travel times within the POD.

3.1.2 TOPOFF 3

During the week of April 4th, 2005, a series of full-scale emergency preparedness exercises named TOPOFF 3 was held around the country. One component of the exercise was a simulated bioterrorism attack in Burlington County, New Jersey. In response to the anthrax outbreak, a POD was activated at Burlington County College in Pemberton, New Jersey. Several student volunteers from the University of Maryland, along with emergency planners from Montgomery County DHHS, were on hand to perform a time study.

Prior to the opening of the POD, its layout was recorded, including measurements of walking distances and queueing space, as marked off by chains and stanchions. During the operation of the POD, resident service times were recorded at each station, and queue lengths were recorded periodically. As residents entered the POD, each received a station visit form, stamped with their arrival time. Since insufficient volunteers were available to give time stamps at every table, residents were asked to record the stations they visited in order on the form. As they left the POD, residents turned in their forms, which were then stamped with a departure time. This allowed us to track the total time residents spent in the POD as well as the likelihood of various routings through the POD.

3.1.3 Seasonal flu clinic

On November 2, 2005, Montgomery County, Maryland held a seasonal flu clinic. For a fee, the county provided vaccinations to anyone who wanted them. Several student volunteers from the University of Maryland were present to do a third time study. When they arrived at the POD, residents received a card with a number on it. The numbers were used to track how many residents received shots and to keep them in order; an arrival time was also stamped on the card as it was handed to the resident. After each resident had been vaccinated, his or her card was collected and stamped with a departure time. If residents traveled through the POD as a family, the group size was noted on the first card of the set. Data was also recorded on the service times at the registration and vaccination stations. The vaccination service times were separated into times for vaccinating adults, times for vaccinating children, and times for vaccinating mixed groups.

3.2 Discrete-event simulation model

Discrete-event simulation models were created using Rockwell Software's Arena 5.0 ®. They were used to model PODs as a network of processes, linked by probabilistic routings that included walking time. The Process Analyzer software included with Arena was used to manage the running of multiple scenarios and the tabulation of their results. These results included the calculation of a 95% confidence interval on all measured responses; the simulation run lengths and numbers of replications were chosen in order to ensure that confidence intervals were less than 5% of the associated response.

3.3 Queueing network approximation models

Daniel Cook's work during the summer of 2004 established the usefulness of simulation models to public health officials in Montgomery County. However, practical considerations make it difficult for health officials to continue using this strategy. As developed in Arena, the models require an expensive software package to run – one with which most public health personnel are not familiar. Even granted the ability to run the models, long run times are implicit in the use of simulations, and drawing conclusions from the massive output generated by Arena can be difficult.

An alternative to building simulation models is to model the POD mathematically, using spreadsheet software that most planners have already been exposed to and use on a regular basis. Building the model in Microsoft Excel® reduces the cost and learning barriers for health departments. Excel can evaluate the mathematical approximations nearly instantaneously, allowing dynamic manipulation of parameters without a delay before feedback is given. Finally, Excel can present all of the relevant information through an interface that is easily understandable, while the calculations are performed behind the scenes.

The travel of residents through a POD can be readily modeled using simple traffic-flow equations. The difficult part is evaluating the amount of time residents spend waiting for service; the equations discussed in the previous chapter provide reasonable approximations for this queueing time. An open Jackson network of service nodes represents the POD; residents enter the system, visit a series of nodes where they wait for service, and leave the system when they have completed their routing. Given an arrival process, service time distributions for each node, and a routing matrix, the steady-state condition of the system can be determined with reasonable accuracy.

There are several situations examined in this thesis that the existing analytical models cannot fully describe. In these situations, I propose refinements which will extend the models to cover the type of queue in question; simulation models of the situation are built, and are used to validate the proposed models.

3.4 Spreadsheet model

The spreadsheet approach to POD modeling was originally investigated in the context of reproducing Cook's simulation model results in a format accessible to the health planners of Montgomery County, as discussed above. The spreadsheet model used traffic flow equations to establish a minimum number of servers required to meet a certain demand for treatment in a given period. It also employed queueing approximations to estimate other aspects of POD performance, such as the time residents spent waiting at each station; by Little's Law (Little, 1961), time in queue can be used to obtain the length of each queue. Distributions for process times at each station were taken directly from the time study of the Dagwood Exercise. A functionally identical model of Burlington County's TOPOFF 3 exercise was also constructed.

During the summer of 2005, planners at Wicomico County asked the CIM lab to create a model of a POD described in their emergency plans. The planners had not tested the plans yet, so no data on processing times were available. However, the station descriptions they provided suggested that their functions would correspond closely to several of the stations used in the Montgomery and Burlington County models. We brought together those stations to create a new model, which helped them to determine how many staff they needed for the full-scale exercise they ran later. This occurrence made it apparent that the data we had collected could be used in the context of other PODs; we could let users piece the distributions for various station types together into models that closely reflected their own plans.

3.5 Validation

Performance estimates from the queueing network approximation models could not be directly compared to the POD performance measured during time studies of exercises, because the exercises were run only for short periods. Instead, simulation models were constructed; they were run starting with no residents in the POD to make them directly comparable to the time study data for validation. Once validated, they could be run for longer periods, with startup time ignored, so that they could be compared to the steady-state queueing network approximation models.

Chapter 4: Analysis of time study data

The performance data that we collected during each of the three time studies had to be converted into a useful form before it could be incorporated into the various models. I tabulated the results in Microsoft Excel ®, and used an Arena tool called Input Analyzer to fit random distributions to the data.

4.1 Statistical approach

I used the Input Analyzer tool included with Arena to fit distributions to the data; this package automatically performs a Kolmogorov-Smirnov (KS) test, and establishes a p-value for the distribution in question. The KS test measures the largest difference between the experimental data and the fitted distribution; this value D is compared to a table of critical values for the given level of significance (Miller, 1985). The null hypothesis (H_0) states that the data and the fitted distribution are the same; if D is less than the critical value, there is insufficient evidence to reject H_0, and we must proceed as if the data match the distribution. The table describing the data from each exercise includes both D and the p-value calculated by the Input Analyzer, along with the critical value for the sample size of each station, calculated at the 0.10 level of significance. These distributions are not used in the analytical models, but instead are used to produce random variables in the simulation models which are built to validate the analytical models.

For each station, the fit of a gamma distribution was tested. I selected the gamma distribution for two main reasons. First, the gamma distribution is positively skewed, which makes it qualitatively appropriate for service processes, which will generally take some amount of time but in some cases may take significantly longer.

Second, the parameters defining the distribution are easily calculated using the mean and variance of a process, as discussed in Chapter 6. Figure 4.1 illustrates the probability density function (PDF) for a typical gamma distribution. The expression for the gamma distribution is given in (4.1).

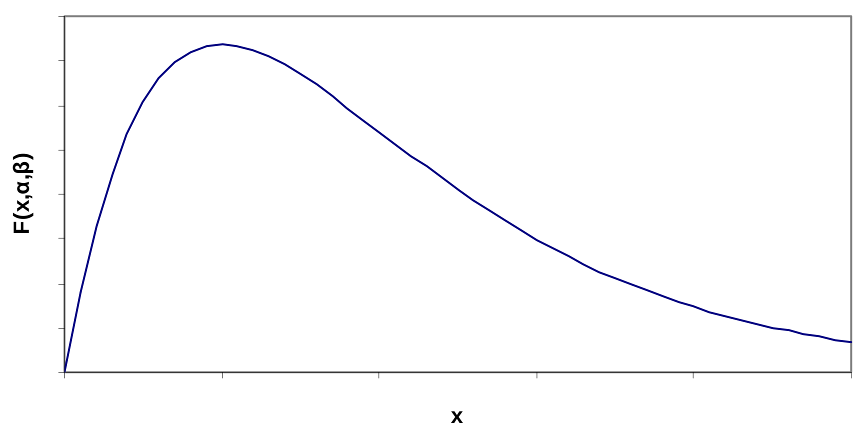

Figure 4.1. A sample gamma distribution.

$$f(x) = \begin{cases} \dfrac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} & \text{for } x > 0, \alpha > 0, \beta > 0 \\ 0 & \text{elsewhere} \end{cases} \tag{4.1}$$

$$\text{where} \quad \Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1} e^{-x}\, dx$$

4.2 Dagwood exercise

The performance data collected at the Dagwood exercise was originally compiled and analyzed by Tyson Cook. The smallpox clinic exercised consisted of the six main flow stations listed below, along with separate isolation rooms for symptomatic residents and those who have had contact with a disease agent. Table 4.1 lists the mean, standard deviation (σ), and SCV of the service times observed at each station. The KS test statistic D is given, along with the critical value and the p-value automatically calculated by the Input Analyzer software, for the fit of the gamma distribution to the data.

- Triage: Members of the triage station staff ask residents whether they have any symptoms of smallpox (a rash or fever) or know they have been exposed to the smallpox virus.
- Registration: residents obtain registration forms and printed information on smallpox.
- Education: residents watch a short briefing video in classrooms while completing their forms.
- Medical screening: medical personnel check residents' registration forms and direct residents with possible complications based on their medical histories to visit the consultation station. The remaining residents sign consent forms and go directly to the vaccination station.
- Medical consultation: residents discuss possible complications with a doctor. Those who refuse the vaccination receive an information sheet and leave the clinic. They will be monitored by public health officials. Those who decide to be vaccinated sign consent forms and go to the vaccination station.
- Vaccination: a vaccination nurse verifies that the consent form has been signed and witnessed and then vaccinates the resident. Another staff member and the resident review an information sheet about what to do after the vaccination, and then the resident leaves the clinic.

Table 4.1. Dagwood exercise performance data.

Station	Mean service time	σ	SCV	D	Critical value	Gamma p-value
Triage (sec)	15.60	5.74	0.1354	0.1580	0.264	>0.15
Registration (sec)	7.29	4.82	0.4372	0.2080	0.438	>0.15
Education	31.20	4.34	0.0193	0.1460	0.064	<0.01
Screening (min)	1.72	0.55	0.1034	0.2720	0.411	>0.15
Consultation (min)	3.77	2.31	0.3754	0.0761	0.230	>0.15
Vaccination	3.60	1.11	0.0951	0.0972	0.224	>0.15

There are several points that should be noted about the performance of these stations. All of the service processes have SCV well below one; this is considered "low" variability. Although none of the stations falls within the range where the Input Analyzer can provide precise p-values, it is apparent that the fit provided by the gamma distribution cannot be rejected, except at the education station. At this station, all residents watch a short video; the only variation in the service times relates to the process of entering and exiting the classroom. Accordingly, this station is better modeled as a constant plus an exponentially distributed random variable.

4.3 TOPOFF 3

The setup of the TOPOFF 3 exercise was more complicated than the design used for Dagwood. Residents arrived at a Pre-POD facility in a separate building, where they received forms and instructions. After completing their forms, they proceeded to the main POD area. At the Reception station, staff members checked residents' forms, and then directed them to follow one of two paths: Main or Fast Track (FT). The Main group proceeded to Registration, Screening, Consultation (if necessary), Education, and Dispensing. The FT group visited a separate Registration station, then received their medication at Dispensing before exiting. The stations are described in detail below; Table 4.2 lists the mean, standard deviation (σ), and SCV of the service times observed at each station. The KS test statistic D is given, along with the critical value and the p-value automatically calculated by the Input Analyzer software, for the fit of the gamma distribution to the data.

- Registration: staff members examine forms in detail, and then refer residents to Screening or Education if they have questions.
- Education: staff members answer general questions about the disease and the treatment.
- Screening: staff members respond to residents with medical concerns, and direct residents with complicated medical issues to Consultation.
- Consultation: doctors assist residents with more complex medical questions.
- Dispensing: staff distributes the appropriate medication to residents.

Table 4.2. TOPOFF 3 exercise performance data.

Station	Mean service time (seconds)	σ	SCV	D	Critical value	Gamma p-value
Reception	74.2	70.3	0.897641	0.115	0.198	>0.15
Main Registration	69.3	42.8	0.381435	0.092	0.183	>0.15
FT Registration	35.1	24.9	0.503251	0.141	0.203	>0.15
Screening	105.0	90.9	0.749461	0.108	0.140	>0.15
Consultation	226.0	160.0	0.501214	0.114	0.176	>0.15
Education	78.8	44.0	0.311783	0.107	0.163	>0.15
Main Dispensing	63.2	35.6	0.317297	0.133	0.148	0.0939
FT Dispensing	80.5	45.8	0.323697	0.225	0.139	<0.01

As with the Dagwood exercise, all stations in the TOPOFF 3 clinic had SCV<1, indicating processes with low variability. The fit of the gamma distribution again can only be rejected at one station, Fast Track Dispensing. Residents who arrive at this station have already been filtered at reception, so that the variation in service times is greatly reduced; every distribution checked by the Input Analyzer produces a fit that the KS test rejects.

4.4 Seasonal flu clinic

The seasonal flu clinic run by Montgomery County was by far the simplest of the clinics I examined. Each resident received a numbered index card upon arrival, for the purpose of managing clinic flow and tracking the number of residents treated. Staff called groups by number to proceed to the Forms station, where residents completed a brief medical history. Upon completion, residents notified a staff member, who checked the form before directing the resident to the vaccination area. Here, residents received vaccinations, then turned in their number and proceeded to a payment station (not included in the model) before exiting the clinic.

Table 4.3. Performance data from seasonal flu clinic.

Station	Mean service time (seconds)	σ	SCV	D	Critical value	Gamma p-value
Forms	255.0	115.0	0.203383	1.02	0.388	<0.01
Vaccination	134.0	55.5	0.171544	0.78	0.240	>0.15

The performance data from the seasonal flu clinic continues the trends exhibited in analysis of previous time study data. All processes have low variability; the Input Analyzer analysis shows that the fit of the gamma distribution cannot be rejected at the Vaccination station, but is not acceptable at the Forms station. At the Forms station, many residents required only the minimum time to complete their medical histories; as service time increased, the relative frequency decreased, so that a triangular distribution is a more appropriate fit for the data.

4.5 Discussion

Analysis of the performance data collected at several time studies has demonstrated several things. First, service processes in the PODs observed tend to have low variability. This makes sense, since staff members are performing a single task repeatedly, in a manner that does not change significantly from one resident to the next. Next, while the gamma distribution was a poor fit for some stations due to the nature of the activities performed there, overall it provides a generally satisfactory approximation of service at most stations studied. This is important, because some properties of the gamma distribution make it an attractive choice for representing these processes; this will be discussed further in Chapter 6.

Chapter 5: Queueing tools

In order to create a POD model that is generally applicable, some modifications to existing analytical models are necessary. New models are proposed to cover several situations where current models cannot be used and are validated against simulation models. All of the necessary analytical models are put together to model an entire POD, and models are created that can be compared to simulation models of several typical POD types. Two of the models are also compared to models built with other queueing model software packages.

5.1 Refining analytical models

Models exist for batch arrivals to a process where customers are served individually, but only for stations with a single server. There are also no models for stations where batches of different sizes arrive from more than one source. However, models are proposed here to account for the nonstandard nature of these situations, and are compared to simulation models for purposes of validation.

5.1.1 Batch arrivals to a station with multiple servers

As mentioned in Chapter 2, Hopp and Spearman (2001) suggested, and Curry and Deuermeyer (2002) demonstrated, that a batch arrival process can be accurately modeled by representing the batches of size k_a as customers of a process with service time $k_a\tau$, and scaling process and arrival SCV by $1/k_a$. In order to extend this result to a station with m servers, the service time must be scaled to the new mean of $k_a\tau/m$. The $1/k_a$ terms in the SCV actually cancel with the additional k_a in the service time, and it turns out that the average time a batch spends waiting in queue is the same amount of time that an individual customer would spend in the queue. We also replace the basic utilization term with the multiple-server form given by Sakasegawa (1977). The approximation for WIBT must be adjusted to accommodate a station with multiple servers, again by scaling the mean service time.

$$CT_q = \left(\frac{c_a^2 + c_e^2}{2}\right)\frac{\rho^{\sqrt{2m+2}-1}}{(1-\rho)}\frac{\tau}{m} \tag{5.1}$$

$$WIBT = \frac{(k_a - 1)}{2}\frac{\tau}{m} \tag{5.2}$$

To demonstrate the accuracy of this approximation, it is compared to an equivalent simulation model. In the simulation, batches hold in a queue until a server becomes available, at which point they are "opened" and individual entities enter the server's queue (Figure 5.1). This extra step in the simulation logic allows the components of waiting time to be examined separately.

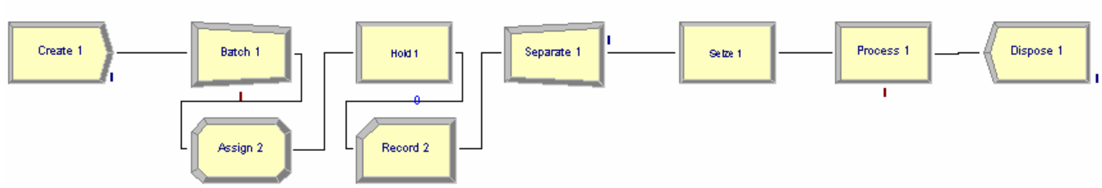

Figure 5.1. Simulation logic for dividing "waiting time" into time queueing as a batch and wait-in-batch-time.

The results of the simulation are given in Table 5.1, along with the values obtained using the proposed approximations for both portions of the waiting time. The magnitude of error between the two is given as a percentage of the simulation value, as is the relative width of the 95% confidence interval Arena calculated for each of the performance measures (denoted by CI).

Table 5.1. Experimental results for batches arriving exponentially to an exponential service process.

k_a	m	ρ	τ (min)	Simulation WIBT (min)	Predicted WIBT (min)	CI	Error	Simulation CT_q (min)	Predicted CT_q (min)	CI	Error
5	1	99%	0.033	0.067	0.067	0.00%	0.0%	10.2	9.901	4.48%	2.9%
		95%	0.033	0.067	0.067	0.00%	0.0%	1.92	1.900	0.78%	1.0%
		90%	0.033	0.067	0.067	0.00%	0.0%	0.901	0.900	0.40%	0.1%
		80%	0.033	0.067	0.067	0.00%	0.0%	0.399	0.400	0.23%	0.3%
		50%	0.033	0.067	0.067	0.00%	0.0%	0.1	0.100	0.14%	0.0%
	3	99%	0.100	0.066	0.067	0.00%	1.0%	9.9	9.819	4.29%	0.8%
		95%	0.100	0.065	0.067	0.00%	1.0%	1.86	1.821	0.93%	2.1%
		90%	0.100	0.063	0.067	0.00%	11.1%	0.84	0.825	0.50%	1.8%
		80%	0.100	0.058	0.067	0.00%	15.5%	0.36	0.332	0.22%	7.6%
		50%	0.100	0.045	0.067	0.00%	38.9%	0.06	0.056	0.18%	6.1%

The WIBT model from (5.2) provides an exact match to values obtained from the simulation for m=1; however, for m>1, the degree of error increases as utilization decreases. This is an interesting result; the discrepancy is caused by the increased likelihood that a batch will find more than one server idle when it arrives at the service process. A model for this phenomenon is discussed in 5.1.2. Despite this discrepancy, the model still provides a useful upper bound on WIBT, and is reasonably accurate for ρ>90%.

The approximation for batch queueing time given in (5.1) provides excellent results for Markovian arrival and service processes with a single server, even outside the stated limits on utilization mentioned by Hopp and Spearman (2001); at 99% utilization, the predicted value is within 3% of the simulation result. When multiple servers are present, the issue discussed above leads to a corresponding reduction in the mean service time for batches, and hence in the time batches spend in queue. While this reduces the model's accuracy somewhat, the predicted queue time is still valid as an upper limit.

A Markovian process is a good approximation for resident arrivals to the clinic, but, as discussed in Chapter 4, all performance data collected for service times indicated that the SCV was significantly less than one. Accordingly, a second batch of experiments was run to verify the models' performance under realistic conditions, with $c_e^2 < 1$. A uniform distribution was used for the service process; the upper and lower boundaries on the service time were set to 140% and 60% of the service time, respectively, yielding an SCV of 0.213 for the service process. Table 5.2 gives these results.

Table 5.2. Experimental results for batches arriving exponentially to a service process with SCV=0.213.

k_a	m	ρ	τ (min)	Simulated WIBT (min)	Predicted WIBT (min)	CI	Error	Simulated CT_q (min)	Predicted CT_q (min)	CI	Error
5	1	99%	0.033	0.067	0.067	0.00%	0.5%	8.570	8.603	3.54%	0.4%
		95%	0.033	0.067	0.067	0.00%	0.5%	1.601	1.651	0.74%	3.1%
		90%	0.033	0.067	0.067	0.00%	0.5%	0.759	0.782	0.40%	3.0%
		80%	0.033	0.067	0.067	0.00%	0.5%	0.337	0.348	0.20%	3.1%
		50%	0.033	0.067	0.067	0.00%	0.5%	0.084	0.087	0.13%	3.4%
	3	99%	0.1	0.066	0.067	0.00%	1.0%	8.566	8.532	4.14%	0.4%
		95%	0.1	0.065	0.067	0.00%	2.6%	1.569	1.582	0.73%	0.8%
		90%	0.1	0.064	0.067	0.00%	4.2%	0.730	0.717	0.39%	1.8%
		80%	0.1	0.061	0.067	0.00%	9.3%	0.312	0.289	0.21%	7.4%
		50%	0.1	0.053	0.067	0.00%	25.8%	0.067	0.049	0.16%	27.0%
20	1	99%	0.008	0.079	0.079	0.00%	0.2%	8.272	8.339	3.24%	0.8%
		95%	0.008	0.079	0.079	0.00%	0.2%	1.587	1.600	0.77%	0.8%
		90%	0.008	0.079	0.079	0.00%	0.2%	0.753	0.758	0.41%	0.7%
		80%	0.008	0.079	0.079	0.00%	0.2%	0.334	0.337	0.24%	0.9%
		50%	0.008	0.079	0.079	0.00%	0.2%	0.084	0.084	0.11%	0.3%
	3	99%	0.025	0.079	0.079	0.00%	0.2%	8.295	8.270	3.37%	0.3%
		95%	0.025	0.079	0.079	0.00%	0.2%	1.585	1.534	0.74%	3.2%
		90%	0.025	0.078	0.079	0.00%	1.5%	0.742	0.695	0.37%	6.4%
		80%	0.025	0.077	0.079	0.00%	2.8%	0.327	0.280	0.20%	14.4%
		50%	0.025	0.075	0.079	0.00%	5.6%	0.079	0.047	0.13%	40.0%

The results of this test generally follow the form of the experiment with exponential service times; for a single server, WIBT is exact and the predicted queue time gives a good estimate of the simulated queue time. For multiple servers, the accuracy of the models is reduced, although to a lesser extent than when exponential service times are used.

5.1.2 Wait-in-batch time with multiple servers

When multiple servers are processing residents who arrive in batches, there is some probability that more than one server will be idle when a batch arrives. When this happens, the WIBT for the members of that batch is reduced accordingly, and the queue time for subsequent batches is affected. This situation can be described by a binomial probability distribution; each server is either busy, with probability ρ, or idle, with probability 1-ρ. We can calculate the WIBT for each possible number of available servers *n* by summing the time each remaining member of the batch waits for service and dividing it by the batch size; this is multiplied by the probability that *n* servers will be available. Summing this across the entire range of *n*, we divide it by the probability that at least one server will be idle (the condition that causes the batch to leave the batch queue and split into individuals), as shown below.

$$WIBT = \frac{1}{\left(1-\rho^m\right)} \sum_{n=1}^{m} \left[\frac{m!}{n!\left(m-n\right)!} \rho^{m-n} \left(1-\rho\right)^n \sum_{x=1}^{k-n} \frac{x\tau}{mk} \right]$$

$$WIBT = \frac{1}{\left(1-\rho^m\right)} \sum_{n=1}^{m} \left[\frac{m!}{n!\left(m-n\right)!} \rho^{m-n} \left(1-\rho\right)^n \frac{\tau}{mk} \frac{\left(k-n\right)\left(k-n+1\right)}{2} \right] \qquad (5.3)$$

This model neglects the probability that a batch will arrive to find no servers available, in which case, when one becomes available, the standard estimate for WIBT will apply. This is corrected by removing the $1/(1-\rho^m)$ term, and adding the WIBT with the appropriate probability:

$$WIBT = \sum_{n=1}^{m}\left[\frac{m!}{n!(m-n)!}\rho^{m-n}(1-\rho)^{n}\frac{\tau}{mk}\frac{(k-n)(k-n+1)}{2}\right]+\rho^{m}\frac{\tau}{m}\frac{(k-1)}{2} \quad (5.4)$$

Applying this model to the results shown above provided a good approximation of WIBT over a range of service processes; although it still was not perfect, it demonstrated clear improvement over the original results. Table 5.3 gives the results; the model gave predictions to within 5% of the actual value for both a uniform and a gamma service process, although the error was higher for the exponential arrival. It is interesting to note that the incorrect approximation in (5.3) gave a slightly better result; for instance, with exponential service at 50% utilization, the error was approximately 8%, compared to the nearly 13% error shown below for those conditions. However, since it is impossible to justify the derivation of this equation, I was forced to write it off as a coincidence.

Table 5.3. Comparison of improved WIBT model.

m	k	c_e^2	ρ	τ (min)	Simulation WIBT (min)	Predicted WIBT (min)	Error
3	5	0.213	99.0%	0.1	0.066	0.067	1.00%
			95.0%	0.1	0.065	0.066	2.26%
			90.0%	0.1	0.064	0.066	2.97%
			80.0%	0.1	0.061	0.064	4.48%
			50.0%	0.1	0.053	0.051	4.09%
		1	99.0%	0.1	0.0663	0.0667	0.54%
			95.0%	0.1	0.0646	0.0665	2.90%
			90.0%	0.1	0.0626	0.0659	5.27%
			80.0%	0.1	0.0584	0.0637	9.13%
			50.0%	0.1	0.0451	0.0508	12.71%
		2	99.0%	0.1	0.0664	0.0667	0.39%
			95.0%	0.1	0.0652	0.0665	1.95%
			90.0%	0.1	0.0638	0.0659	3.29%
			80.0%	0.1	0.0609	0.0637	4.65%
			50.0%	0.1	0.0519	0.0508	2.06%

The performance of the new approximation for WIBT with m>1 is not as good as the estimates for a single-server system; however, it is a significant improvement over simply scaling the single-server model to the new mean service time. While it is useful for providing accurate estimates of WIBT, it is not something that can be easily implemented in the spreadsheet model, since a table of summations would have to be regenerated every time the number of servers at a station was changed. The simple approximation, which provides an excellent estimate of the upper limit on WIBT, will have to be sufficient for planning purposes until a simpler approximation is formulated. It should be considered that the experiments detailed above all employed an exponential arrival process; this means that the fraction of arriving batches encountering each server state is equal to the probability of that server state existing (Wolff, 1982). This condition (known as PASTA, for Poisson Arrivals See Time Averages) would not apply under other arrival conditions, and (5.4) might provide a less accurate estimate of WIBT.

5.1.3 Multiple batch arrival streams

The approximations discussed above are applicable to a station with a single input stream of batches; however, in a queueing network, it is possible that batches will arrive from multiple stations, each with a different batch size. Models for a mixed input of this sort do not appear to exist, so I will propose a new one here. My approach is to use routing probabilities to aggregate the different batch sizes of the input stream to form an aggregate batch size $\overline{k}_a$, and use this as an input to (5.2). Since the approximation is linear with regard to k_a, the result is the same as if we sum the probability-weighted outcomes of the wait-in-batch times produced by the different batch sizes. The proposed equation for aggregate batch size is:

$$\bar{k}_{a,i} = \sum_{j=1}^{i-1} k_{p,j} \frac{\lambda_j \cdot q_{ji}}{\lambda_i} \tag{5.5}$$

This equation calculates the aggregate batch size from the perspective of customers in the batch, based on the proportion of the total flow rate associated with each batch size (*N.B.*: this is slightly different from weighting batch sizes by their proportion of the total number of batches that arrive, which gives a mean batch size from an external perspective). This aggregate batch size gives an excellent performance in estimating WIBT; Table 5.4 below gives the performance of several simulations with multiple batch arrival streams, along with the results predicted using aggregate batch size as an input to (5.2). These experiments were performed on an M/M/1 system.

Table 5.4. Experimental results for multiple batches arriving to a single server (all λ given in entities per minute).

k_{a1}	λ_1	k_{a2}	λ_2	k_{a3}	λ_3	k_{a4}	λ_4	λ	$\bar{k}_a$	τ (min)	Simulation WIBT (min)	Predicted WIBT (min)	Error
1	5	5	10	0	0	0	0	15	3.667	0.050	0.0670	0.0667	0.50%
1	10	10	10	0	0	0	0	20	5.500	0.048	0.1064	0.1069	0.45%
1	5	3	9	4	12	5	3	29	3.246	0.033	0.0396	0.0374	5.49%
1	5	20	20	20	40	10	15	80	16.938	0.012	0.0946	0.0946	0.03%

These results make clear that the aggregate batch size approach provides excellent estimates of the performance of a station where batches of different sizes arrive from multiple sources. However, the model does not include any mechanism for incorporating the variability in batch sizes, which might be used to define a range of likely values for WIBT.

5.2 Complete queueing model framework

With the unusual situations accounted for, a complete framework for constructing queueing models can now be described. Demand for service is calculated with user inputs for the total number of customers to be served (population) and how long they have to be serviced (treatment time). We use i throughout to denote individual stations, with 0 referring to the bus arrival process, 1 through "I" referring to the stations in the clinic, and "I +1" referring to the exit.

5.2.1 Inputs

P = Size of population to be treated (residents)

L = Time allotted for treatment (days)

h = Daily hours of operation (hours per day)

N = Number of clinics

m_i = Number of staff at station i

τ_i = Mean process time at station i (minutes)

σ_i^2 = Variance of mean service time at station i (minutes^2)

$k_{p,i}$ = Processing batch size at station i

d_{ij} = Distance from station i to station j (feet)

v = Average walking speed (feet per second)

q_{ij} = Routing probability from station i to station j

k_0 = Bus arrival size

$c_{a,1}^2$ = Arrival SCV at station 1

5.2.2 Outputs

λ_i = Arrival rate at station i (residents per minute)

$c_{a,i}^2$ = Arrival SCV at station i

$c_{e,i}^2$ = Processing time SCV at station i

$c_{d,i}^2$ = Departure SCV at station i

TH' = Required throughput (residents per minute)

m_i' = Minimum staff at station *i*

CT_i = Cycle time at station *i* (minutes)

CT = Total average time in clinic (minutes)

WIP = Average number of residents in clinic

R = Clinic capacity (residents per minute)

$CT_{q,i}$ = Average time in queue at station *i* (minutes)

W_i = Average time spent traveling to the next station after station *i* (minutes)

Q_i = Average queue length at station *i*

ρ_i = Utilization at station *i*

5.2.3 Equations

The throughput required to treat the population in the given time is $TH' = \frac{P}{60LhN}$.

If residents arrive individually, the user specifies the arrival variability c_{a1}^2. Else, the individual resident arrival variability is given as $c_{a1}^2 = k_0 - 1$.

All arriving residents go to the first station. We calculate the arrival rates for the other stations based on the routing probabilities:

$$\lambda_i = \begin{cases} TH' & i = 1 \\ \sum_{j=1}^{i-1} \lambda_j q_{ji} & i > 1 \end{cases}$$

At each station after the first, we calculate arrival batch size based on the process batch size of the previous stations: $\overline{k}_{a,i} = \begin{cases} k_0 & i = 1 \\ \sum_{j=1}^{i-1} k_{p,j} \frac{\lambda_j \cdot q_{ji}}{\lambda_i} & i > 1 \end{cases}$

We use station arrival rates to determine the minimum staff at each station: $m_i' = \frac{\lambda_i \cdot \tau_i}{\bar{k}_{a,i}}$

We then use user-selected staff levels m_i to calculate station utilization: $\rho_i = \frac{\lambda_i \cdot \tau_i}{m_i \cdot k_{p,i}}$.

We calculate the variability of arrivals, processes, and departures from each station:

$$c_{a,i}^2 = \sum_{j=1}^{i-1} \left(\left(c_{d,j}^2 - 1 \right) \cdot q_{ji} + 1 \right) \cdot \frac{\lambda_j \cdot q_{ji}}{\lambda_i}$$

$$c_{ei}^2 = \frac{\sigma_i^2}{\tau_i^2}$$

$$c_{d,i}^2 = k_{p,i} - 1 + k_{p,i} \left(1 + \left(1 - \rho_i^2 \right) \left(\frac{c_{a,i}^2}{k_{p,i}} - 1 \right) + \frac{\rho_i^2}{\sqrt{m_i}} \left(c_{e,i}^2 - 1 \right) \right)$$

The average time spent waiting at station *i* depends upon the arrival and process batch sizes; denotes time waiting for service, while $WIBT_i$ represents time waiting in arrival batches and $WTBT_i$ represents time waiting to form a process batch.

$$\begin{cases} CT_{q,i} = \frac{1}{2} \left(\frac{c_{a,i}^2}{k_{p,i}} + c_{e,i}^2 \right) \left(\frac{\rho_i^{\sqrt{2m_i+2}-1}}{(1-\rho_i)} \right) \frac{\tau_i}{m_i} & \text{for } k_{p,i} > 1, k_{a,i} = 1 \\ CT_{q,i} = \left(\frac{c_{a,i}^2 + c_{e,i}^2}{2} \right) \frac{\rho^{\sqrt{2m+2}-1}}{(1-\rho)} \frac{\tau_i}{m_i} & \text{for } k_{p,i} = 1, k_{a,i} \geq 1 \end{cases}$$

$$WTBT_i = \frac{k_{p,i} - 1}{2\lambda_i}$$

$$WIBT_i = \frac{\left(\bar{k}_{a,i} - 1 \right)}{2} \frac{\tau_i}{m_i}$$

The average time spent traveling to the next station after station *i* depends upon the routing probabilities and the average walking speed:

$$W_i = \frac{1}{60v} \sum_{j=i+1}^{I+1} q_{ij} d_{ij}$$

The cycle time at station ***i*** is $CT_i = CT_{q,i} + WIBT_i + WTBT_i + t_i + W_i$.

We weight the station cycle times by their arrival rates to calculate the total average time in clinic:

$$CT = \frac{1}{\lambda_1}\sum_{i=1}^{I}\lambda_i CT_i$$

Other statistics we calculate include clinic capacity, the average queue length at each station, and the average clinic WIP:

$$R = \min_{i=1,\ldots,I}\left\{\frac{m_i\lambda_1}{\tau_i\lambda_i}\right\}$$

$$Q_i = CT_{q,i}\lambda_i$$

$$WIP = \lambda_1 \cdot CT$$

5.3 Validating analytical models

With the gaps in the available analytical models filled, I combined the various equations to create the Clinic Planning Model Generator software. This Excel-based software takes input from users to determine the demand for treatment at each POD site, and asks the user to select the stations that will be included in the model. A detailed description of the user guide for the software is included in Appendix A. Two typical clinic setups are evaluated here: a smallpox vaccination clinic, such as the one set up during the Dagwood exercise, and a simple model proposed for a pandemic flu vaccination clinic.

5.3.1 Smallpox vaccination clinic

Among the first applications of the analytical queueing models was the construction of a model of the Dagwood exercise for use by the planners at

Montgomery County. The model consists of all the stations discussed in 4.1, with routing probabilities between stations as given in Table 5.5. Arrival rates were set to coincide with 95% of clinic capacity. Buses holding 50 residents arrived according to an exponential distribution; in the analytical model, a batch arrival represented this process. In order to validate the queueing model, I compared it to the simulation model constructed by Tyson Cook.

Table 5.5. Routing probabilities in Dagwood Exercise.

To	From Triage	Symp.	Contact	Reg.	Education	Screening	Cons.	Vacc.
Symptoms	4.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Contact	3.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Registration	92.1%	67.0%	65.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Education	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%
Screening	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Consulting	0.0%	0.0%	0.0%	0.0%	0.0%	26.2%	0.0%	0.0%
Vaccination	0.0%	0.0%	0.0%	0.0%	0.0%	73.8%	94.1%	0.0%
Exit	0.0%	33.0%	35.0%	0.0%	0.0%	0.0%	5.9%	100.0%

Since both models specified mean times for service processes directly, the cycle time results are less interesting than those for queueing time. Table 5.6 and Figure 5.2 compare the outputs of the analytical and simulation models; Analytical (old) refers to the results produced using the queueing models discussed in Chapter 2, while Analytical (new) makes use of the models developed in 5.1. The analytical models do not provide a perfect match, particularly in the case of the individual service stations following education; however, using the analytical models developed in 5.1 generally improves the results, compared to the analytical models described in Chapter 2. The discrepancy in results for the final stations in the clinic is caused by the extreme variability introduced by batching at the education station; modeling the vaccination clinic without this batching leads to much better agreement between the models. When compared to vaccination, the screening and consultation stations have short service times and low utilization, which tends to reduce the effects of the high arrival SCV at these stations. I would also note at this point that I have observed a trend among clinic planners to remove educational stations with batching where possible, due to the queueing caused by the release of a group of residents all at once.

Table 5.6. Numerical comparison of analytical and simulation model outputs for a vaccination clinic.

	Triage	Reception	Education	Screening	Consulting	Vaccination
Analytical (old)	1.2229	0.024	4.87	33.87	4.64	13.71
Analytical (new)	1.3265	0.0001	3.4082	27.5314	2.9753	11.0623
Simulation	1.5020	0.0020	3.6030	46.4730	1.3430	38.0070
Error (old)	18.58%	1100.00%	35.17%	27.12%	245.50%	63.93%
Error (new)	11.68%	96.72%	5.41%	40.76%	121.54%	70.89%

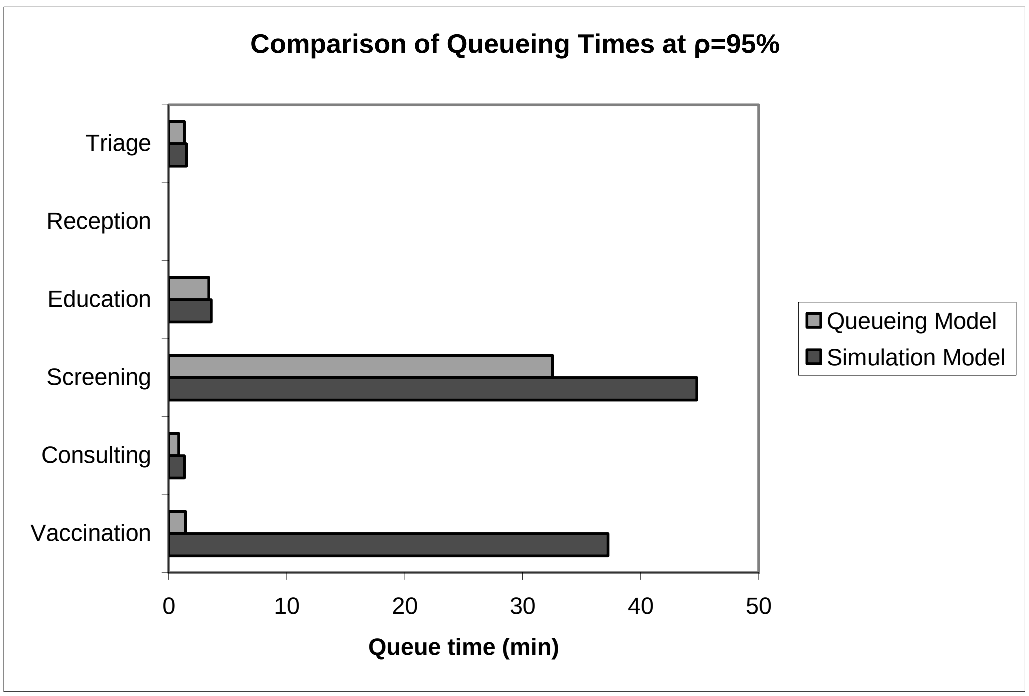

Figure 5.2. Graphical comparison of analytical and simulation model outputs for a vaccination clinic.

5.3.2 Pandemic flu POD

Aaby, et al. (2006b) proposed the pandemic flu vaccination POD described here. It includes only two stations: triage and vaccination. The triage station includes registration, and the vaccination station includes limited education and screening. At the triage station, nurses greet arriving residents and assess their condition. Residents who do not fall within the vaccination criteria and those showing symptoms of an illness (an estimated 2% of the number arriving) are not allowed to enter the POD. Symptomatic residents at triage are redirected to designated medical facilities. The remaining residents (98% of those that visit the triage station) receive a registration form at the triage station and proceed to the vaccination station, where they complete the form and wait for an available nurse or physician. The nurse/physician reviews the form to verify that the resident can safely receive the vaccine, then vaccinates the resident and provides a fact sheet on flu vaccine. The resident then leaves the POD. Figure 5.3 illustrates the routing of the residents.

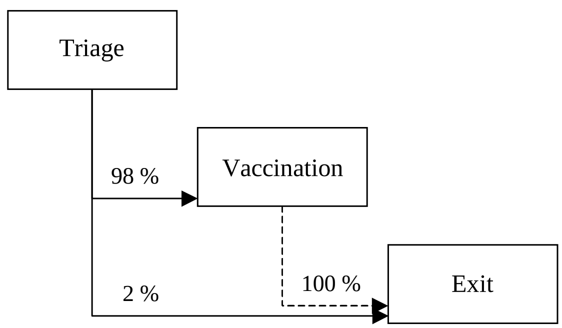

Figure 5.3. Diagram of resident flow in a pandemic flu clinic.

To build the analytical model, several pieces of information were required. The service process data at each of the two stations was based on the performance of equivalent stations at the Dagwood exercise. Approximate walking distances between stations were derived from the proposed POD layout. Preliminary investigation using the analytical model suggested that a staff of two greeters and eighteen vaccination nurses would be sufficient to treat the estimated demand of 10,100 residents in four eight-hour days without creating excessively long queues.

To validate the model, I used a simulation generation tool to create a model in Arena that matched all the details of the analytical model; Chapter 6 describes the tool in detail. The two models were an excellent match, as shown in Table 5.7 and Figure 5.4; the error between the models is within approximately 2% in all measures. In the one statistic where the accuracy of the analytical model is lower (Time in vaccination), the result falls only slightly outside the width of the 95% confidence interval (listed as CI). The results of this comparison demonstrate that the analytical model is a more than acceptable alternative to a simulation model.

Table 5.7. Numerical comparison of analytical and simulation model outputs for a pandemic flu clinic.

Statistic	Simulation time (min)	Predicted time (min)	CI	Error
Total time in clinic	5.3776	5.4500	1.35%	1.30%
Time in triage	0.4901	0.5041	2.86%	2.04%
Time in vaccination	4.3085	4.3683	1.39%	1.62%
Time spent walking	0.6667	0.6701	0.51%	0.00%

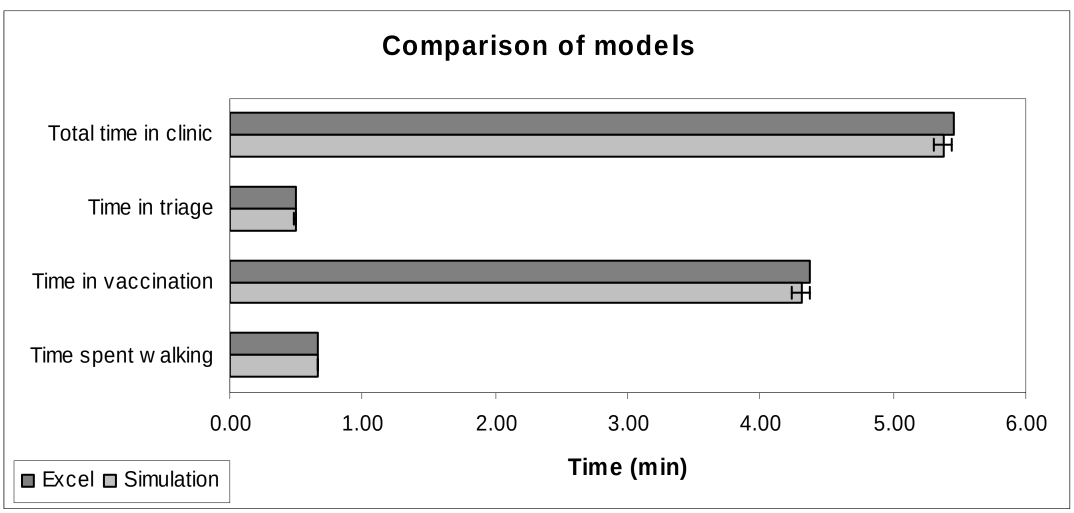

Figure 5.4. Graphical comparison of analytical and simulation model outputs for a pandemic flu clinic.

5.4 Comparison with other packages

In order to validate the spreadsheet modeling tool, two queueing software packages were obtained. These packages were Rapid Analysis of Queueing Systems (RAQS), a Windows application developed at Oklahoma State's Center for Computer Integrated Manufacturing (Kamath et al., 1995), and Queueing Theory Software Plus (QTS-Plus), an Excel-based package authored by James Thompson, Carl Harris, and Donald Gross. RAQS uses the parametric decomposition approach to solving queueing networks (Segal and Whitt, 1989; Whitt, 1983), while QTS-Plus is based around equations from Gross and Harris (1974). Models were also produced with the clinic planning model generator software discussed above.

Models of two different PODs were developed in each of the four packages. Model A (see Table 5.8 below) is based on performance measures from the TOPOFF 3 exercise; most stations are overstaffed, and hence have very low utilizations and short queueing times. Model B (see Table 5.9 below) represents a fictitious POD with more closely controlled parameters; residents here experience longer queues because of higher staff utilization. In RAQS and QTSPlus, each POD was modeled using an open Jackson queueing network with these parameters. Table 5.10 and Table 5.11 below give the routing matrices for the two models. Discrete event simulation models of the two PODs were also created using Rockwell Software's Arena® 5.00. Both models were run with 100 replications of 800 hours; 4 hours of warm-up time were sufficient to achieve steady state.

Table 5.8: Parameters for Model A.

Node	Number of Servers	Service Time (min)	Service Time SCV
1	5	1.237	0.725
2	8	0.585	0.687
3	8	1.34	0.301
4	8	1.154	0.4
5	2	1.304	0.296
6	10	1.752	0.524
7	8	3.765	0.558
8	8	1.051	0.297
9	4	12.698	0.467
10	1	10	0

Table 5.9: Parameters for Model B.

Node	Number of Servers	Service Time (min)	Service Time SCV
1	2	0.259	1.105
2	2	1.752	0.525
3	6	1.154	0.4
4	9	1.752	0.525
5	3	3.765	0.308
6	7	1.34	0.301
7	5	12.698	0.467

Table 5.10. Routing Table for Model A.

	To									
From	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Exit**
1	0.76	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2		0.42	0.39	0.10	0.03	0.00	0.04	0.01	0.00	0.01
3			0.10	0.07	0.01	0.01	0.03	0.00	0.00	0.77
4				0.49	0.31	0.04	0.13	0.01	0.00	0.01
5					0.25	0.07	0.59	0.05	0.00	0.04
6						0.38	0.52	0.05	0.00	0.05
7							0.78	0.08	0.00	0.14
8								0.00	0.01	0.99
9									0.09	0.91
10										1.00

Table 5.11: Routing Table for Model B.

	To						
From	**2**	**3**	**4**	**5**	**6**	**7**	**Exit**
1	0.10	0.90	0.00	0.00	0.00	0.00	0.00
2		0.50	0.00	0.00	0.00	0.50	0.00
3			1.00	0.00	0.00	0.00	0.00
4				0.10	0.90	0.00	0.00
5					0.50	0.00	0.50
6						0.00	1.00
7							1.00

Each POD was tested at several levels of resident arrival, corresponding to 50%, 80%, 90%, 95%, and 99% of POD capacity; Models A and B have capacities of 4.043 and 5.407 residents/minute, respectively. Data was recorded for mean total time and mean queueing time at each node, as well as mean time in system and mean system WIP. Data from the simulation model of the POD was taken as the baseline set. The differences between each model and the baseline set was calculated, and compared with the width of the 95% confidence interval on the simulation data.

5.4.1 Model A results

In Model A, deviations from the simulation model in average total time and average total WIP had the values given in Table 5.12 below. Through every station of the POD and in the total time in system, the RAQS model matched the simulation most closely, although it was still significantly outside the 95% confidence interval of the simulation results. In total WIP, the spreadsheet model provides a better approximation than RAQS for the three scenarios with higher utilization, and even approaches the limits of the 95% confidence interval.

Because the queueing times at most stations were so small, tiny differences were greatly exaggerated in the calculation of results; only stations with longer queueing times are discussed here. Only two stations in this model have queueing times greater than one minute at any of the five arrival rates: Reception and Education. At Reception, all three models are consistent; at Education, the spreadsheet model and the RAQS model are very close to simulation values, though the deviation in the QTS-Plus model is much greater. The last two columns of Table 5.12 contain this data.

Table 5.12: Average differences across scenarios (in minutes) in Model A

	Avg. Total Time	Avg. Total WIP	Reception Queue	Education Queue
Spreadsheet model	2.1454	2.6250	0.2817	0.0201
RAQS	1.0178	3.7260	0.3946	0.1896
QTS-Plus	2.8112	10.6093	0.9206	2.4208
Simulation 95% C.I.	0.2955	1.1874	0.2764	0.1705

5.4.2 Model B results

In Model B, error in the average total time and average total WIP had the values given in Table 5.13 below, along with the average error in queueing times throughout the model. In the POD total statistics, the RAQS model matched the simulation most closely although the spreadsheet model was also well within the 95% confidence interval of the simulation results. For individual stations, the RAQS model was the only one within the 95% confidence interval of the simulation data, but the spreadsheet model was not far off. The estimates of the QTS-Plus model were consistently the least accurate. All of the models become more accurate at higher levels of utilization.

Table 5.13: Average differences across scenarios (in minutes) in Model B

	Avg. Total Time	Avg. Total WIP	Queueing Times (Avg.)
Spreadsheet model	0.1226	0.5900	0.0512
RAQS	0.0730	0.3386	0.0153
QTS-Plus	2.5097	13.1040	0.4780
95% C.I.	0.2146	1.1576	0.0396

It appears that the models built using RAQS provide a better approximation of the simulation models than the spreadsheet models or the QTS-Plus models. However, the inaccuracies of all three models are greatest in situations where the actual time value is insignificant (i.e. below one second). For the stations with longer queueing times, the approximations provided by the three models give a much better estimate of the simulation model results.

In this chapter, I have developed several new queueing approximations, and demonstrated their validity. I then gathered these approximations into a framework for analytical modeling with other queueing models and traffic flow equations, and demonstrated the usefulness of the analytical model by applying it to two POD designs. Both PODs were tested against simulations to validate the analytical model; I also used two other queueing software packages to as points of comparison with two other POD designs. The performance of the new analytical model was satisfactory in all comparisons.

Chapter 6: Turning spreadsheets into simulations

In order to validate the analytical models of queueing networks that were built using Microsoft Excel, it was necessary to create simulation models duplicating their structure and parameters. The repetitive nature of the task and the standardized structure of the POD planning models made automation an appealing option.

6.1 Software concept

Since the clinic planning models have a consistent internal arrangement of data, it was possible to use Arena's application programming interface (API) to automate the process of creating simulation models. This meant that I could quickly build simulation models that always matched the spreadsheet models in every detail; Figure 6.1 shows an example of the simulation model logic generated for a simple two-station flu POD.

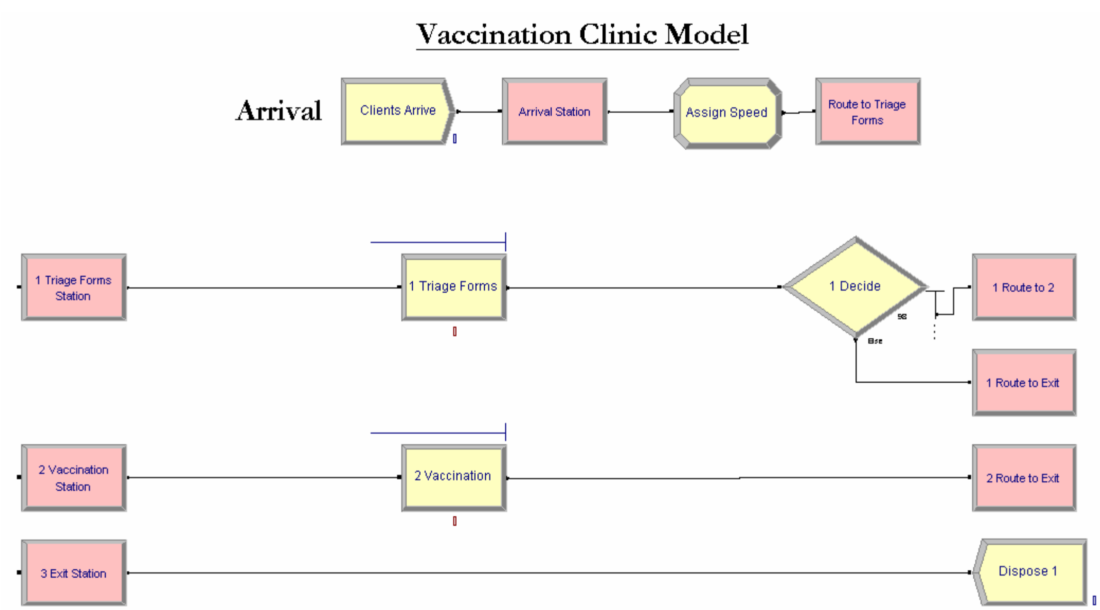

Figure 6.1. Simulation model logic automatically generated for a simple flu vaccination clinic.

The basic operation of the simulation generation software goes as follows:

- Read spreadsheet model and record basic setup information (name, author, arrival rate, etc.), then use these values to customize existing modules in an existing template file.
- Parse the routing and distance tables, recording probabilities and distances into two-dimensional arrays.
- Step through the stations in the model, recording name, number of servers, and service time distribution for each. consists of a Station module (where residents arrive after leaving a Route module at another station), a Process module, and a Decide module that directs residents to one of several Route modules based on routing probabilities.

6.2 Details of implementation

The basic construction of a clinic simulation model involves creating resident arrivals, followed by the service processes they will go through; after each of these, residents must travel to the next process, or to the exit. The time it takes for residents to reach the next station is determined by entering the distance they must travel. Some processes involve extra modules in order to create batch processes.

6.2.1 Arrival and service processes

Resident arrivals to the POD are handled in a straightforward fashion. The initial Create, Assign, and Route modules are pre-configured in an Arena model file, which serves as a template. At runtime, the software checks the spreadsheet model to determine the arrival group size; this can be one if residents arrive individually, or higher if they are transported by bus. The mean interarrival time is also recorded; this value is calculated in the model to help planners with the timing of bus arrivals, but is also correct when applied to the interval between individual arrivals. These values are entered into an existing Create module, which assumes an exponentially distributed arrival process. An Assign module that gives each resident a walking speed is also updated with the appropriate value from the spreadsheet model.

The software also collects the mean (τ) and variance (σ^2) of the service process at each station. It uses these values to calculate the parameters of a gamma distribution. As discussed in Chapter 4, the gamma distribution was found to be an acceptable fit for the data we recorded. The gamma distribution is also attractive because of several qualitative properties. For instance, it is right tail heavy; all service processes performed in a POD require some minimum amount of time, but they can occasionally take longer to complete. The gamma distribution has the additional advantage of using two parameters, so it can accurately represent both the mean and the SCV of a given distribution. Finally, the parameters of the gamma distribution are simple to calculate based on the mean (τ) and standard deviation (σ) of a process. The shape (α) and scale (β) parameters are calculated as follows:

$$\beta = \frac{\sigma^2}{\tau} \qquad \alpha = \frac{\tau}{\beta} \tag{6.1}$$

6.2.2 Routing

After every Process module, there is an “N-way by chance” Decide module. The tool adds branches to this module that direct residents to subsequent stations in the model; it fills these branches with the probabilities from the model’s routing table. Arena permits branches to have zero probability, which allows the simulation to correspond to the routing table exactly, as well as leaving the user the option of adjusting these values after the simulation has been built.

6.2.3 Walking distances

The simulation model also incorporates walking distances from the spreadsheet model. When entries in the distance table are nonzero, an entry is added to a table in the simulation. The corresponding Route module is updated with a transit time for the routing, given by the distance traveled divided by the resident's walking speed.

6.2.4 Process batching

Some stations in a POD may allow groups of residents to be processed at one time. One example is a briefing station, where residents sit and watch an educational video. When such a station occurs in the spreadsheet model, a Batch module is added to the simulation before that station's Process module, and a Separate module is included afterwards. The batch module specifies the batch size as a variable, allowing the user to control it when running scenarios in Arena's Process Analyzer.

Chapter 7: Assessment tools

Providing sufficient personnel to staff a POD is a major factor in the success of a prophylaxis campaign, but it only responds to the "how" portion of a plan. To be fully prepared, a plan should also include the "who," "what," "where," and "when" elements discussed in Chapter 2. Other information must also be included to completely satisfy the "how" of running a POD. If public health staff were to set up and run the POD in question, it would quickly become obvious what elements of the plan they had overlooked or failed to develop fully. In the absence of this physical reality, we must instead examine the two documents that govern the setup and operation of the POD: the plan and the layout.

It was discussed earlier that a POD can be viewed as a type of manufacturing facility; here, I chose to apply another manufacturing tool in order to evaluate POD plans and proposed POD layouts. An industrial assessment tool can estimate the performance of a manufacturing facility based on observations made during a brief plant tour. This method, discussed by Goodson (2002), is known as rapid plant assessment (RPA), and provides a structured way to make an objective evaluation of a production facility. The basic concepts embodied in RPA, along with some of the categories used for evaluation, are well suited for assessing the performance of a POD design. Table 7.1 below lists the RPA categories, along with the equivalent performance measures for a POD. These performance measures were translated into the criteria that formed the basis of two assessment tools. The worksheets for these tools are included in Appendix B.

Planners should use these tools to review the plans and layouts that they have created. Once the planner has completed the initial design phase, the planner (or someone else who will not read between the lines, knowing the intent with which the plan was written) will go through each item on the worksheet and determine whether it is completely satisfied (Complete), partially satisfied (Incomplete), Missing, or Not Applicable. By carrying out this review, planners will be able to evaluate each of these pieces for both completeness and quality.

Table 7.1. Translation of RPA categories to POD assessment

Rapid plant assessment category	POD assessment equivalent
Customer satisfaction	Availability of staff to answer questions; short resident cycle times.
Safety, environment, cleanliness and order	Security measures; NIMS compliance.
Visual management system	Signage; visibility of available servers.
Scheduling system	Management of resident arrivals.
Use of space, movement of materials, and product line flow	Resident flow: queueing space, flow-through stations.
Levels of inventory and work in process	Number of residents in queues.
Teamwork and motivation	Staff comfort and training.
Condition and maintenance of equipment and tools	Layout of supplies at stations; material storage and resupply.
Management of complexity and variability	Frequent review of POD status, with adjustments made where necessary.
Supply chain integration	Integration of distribution from local receiving, staging, and storage sites with clinic operations.
Commitment to quality	

7.1 Plan assessment

There are many elements of vital importance to a good POD plan; these form the bulk of the plan, and are rarely forgotten because of their obviousness. There are also, however, more minor considerations that can make a POD run more smoothly and efficiently. These items are much more likely to be neglected when a plan is formulated, and their absence will only be brought to light by the activation or exercising of the plan.

7.1.1 Plan assessment details

The assessment tool has some basis in the "Overall Planning and Management Checklist" included in Annex 3 of the CDC's Smallpox Response Plan and Guidelines (2002); however, I have endeavored to go beyond this simple checklist by incorporating additional factors which appear to be important, based on my own experiences and those of planners from Montgomery County. Where appropriate, the criteria from Table 7.1 have also been included. By giving planners an assessment tool that includes some of these oft-overlooked elements, I hope to bring them to the planners' attention so that they recognize what they have missed and make the necessary corrections. The worksheet groups the guidelines for examining a plan into four categories: Basic plan, facilities and supplies, personnel, and resident notification and treatment.

Basic plan

Basic guidelines for the POD plan include the following: Define the scope of the plan. Estimate how many residents must be treated, and how long the treatment period will last. Determine which stations are required for an event of this type, and use a flowchart to organize the sequence in which residents will pass through them. Assign responsibility for the maintenance (updating) and activation of each component of the plan to one person. Form agreements with neighboring municipalities where appropriate.

Personnel

Guidelines for staffing a POD include the following: Provide training and exercises so that staff members know their roles and can perform them efficiently. Pre-position medication for treatment of first responders. Create role description sheets that will serve as reminders for staff when a clinic is activated. Identify an organization to handle security at POD sites (e.g. police department, sheriff's department, school security staff).

Facilities and supplies

Guidelines for POD facilities and supply include the following: Identify a command center, vaccine storage location, and approved POD sites. Gather contact information for liaisons at POD sites. Create physical layouts customized for each POD location. Identify the locations of all needed supplies, and determine how they will be transported to PODs. Identify a method of transportation for staff to reach PODs. Create literature and forms that will be distributed to residents at PODs.

Resident notification and treatment

Guidelines for notifying and treating residents include the following: Procedures and agreements for alerting the public of a threat and the proposed response using local media. Use a telephone hotline to answer residents' questions. Identify a scheme to manage the rate and method of resident arrivals at PODs. Provide accommodations for residents with limited mobility.

7.1.2 Evaluation of a typical plan

Two planning documents were available to review using the plan assessment tool: Montgomery County's smallpox mass immunization plan and New Jersey's mass prophylaxis manual. The manual is not a plan as such, but as guidelines for the creation of a plan, it should include recommendations for all the items in the plan. Completed assessment worksheets for the two plans are included in Appendix C.

Montgomery County Mass Immunization Plan

The planners at Montgomery County Public Health are among the more experienced planners in the field of public health; after running numerous exercises and drills, they have created POD plans that include many details beyond those recommended by the CDC (2002).

The basics of the plan are fairly well covered; the plan includes a chart of event sizes and types, along with guidelines for the activation of the plan. The plan describes all the included stations in detail, and flowcharts are included to show resident movements. However, responsibility for sections of the plan does not appear to be assigned; while it may exist in another document, including it in the plan would make the information more readily available. The plan also does not describe any agreements with neighboring jurisdictions within the National Capital Region (NCR); the version of the plan that I reviewed was written before the NCR Matrix (Metropolitan Washington Council of Governments, 2005) was completed, so a newer version may already exist.

Montgomery County's plan received a perfect score in the personnel section of the report; it identifies the staffing levels required for events of various scales, and exercises, treatment of first responders, role descriptions, and security personnel are all present.

Several elements were missing from the facilities and supplies category. No mention is made of the locations of a command center or a secure storage facility; these decisions have certainly been made, but they should be included in this document for ready availability. Forms for residents and physical layouts of POD sites and were also missing, but, again, it is likely that they simply were not included in the document I received. While the document does not include contact information for POD site liaisons, there is a reference to a county Crucial Document File containing the information. The document also does not describe supply location and transportation in any detail; the reader is instead referred to the county's SNS protocol. Waste disposal is included among the criteria for POD sites, and staff access to POD sites is discussed.

The plan does not include any component of resident notification; agreements certainly exist between the county and media outlets, and procedures for using them must also be in place, but neither has been included or directly referenced in this plan. While it addresses resident transportation, no mention is made of the measures taken to make PODs accessible to residents with limited mobility.

Montgomery County's experience in the area of planning PODs is extensive, and this shows in some of the components they chose to include in their plan, such as designating methods of resident arrival, and the training they provide for POD staff. However, there is a lot of material missing from the document. While the missing information is probably contained in other documents, if the entire public health staff was replaced tomorrow, none of the new personnel would know where to look for this information. Once the plan references all of the external documents, it will be much more complete and easier to follow.

New Jersey Mass Prophylaxis Manual

The New Jersey Department of Health and Senior Services (NJDHSS) created the New Jersey Mass Prophylaxis Manual "for the purpose of aiding local health officials in the operation & management of a POD…or Mass Clinic," (NJDHSS, 2005). It is not a POD plan in and of itself, and thus is significantly lacking in detail. Nevertheless, any information that is included in these guidelines would presumably be present in POD plans based upon them; assessing the manual is helpful because it brings up added elements that planners need to consider when they write their plans.

Many basic plan items were not included in the manual, because they describe details specific to a jurisdiction or event. However, the manual does include two of the most important items: a list of POD stations, and a flowchart of resident movement. It discusses a command system that is compliant with FEMA's Incident Command Structure (ICS); however, the National Incident Management System (NIMS) has since superseded ICS, and the manual should be updated to reflect that. If all jurisdictions in New Jersey adhere to the guidelines set forth in the manual, then every neighboring jurisdiction will follow similar procedures; however, formal agreements will strengthen cooperation between communities.

Because the manual does not correspond to a particular department, none of the criteria regarding facilities applies to it. It does include sample forms and literature for distribution to residents, but it makes no mention of signage and direction of residents within a POD, which are vital to maintaining efficient flow.

Although it does not include any details, the manual makes appropriate mention of notification issues such as using mass media and setting up telephone hotlines. As with the facility-specific criteria, general guidelines cannot include memoranda of understanding or specific details for resident arrivals, but they are issues of which planners should be aware.

The area where this manual gives the most helpful information regards personnel. It addresses the need to treat first responders and POD staff in a timely manner, and provides role descriptions and necessary staffing levels. It also recommends the use of local law enforcement for security at POD sites. The manual cannot provide a training schedule for staff, but emphasis on the need to provide regular training and exercises would be beneficial.

The manual is not intended for use as an actual POD plan; it provides guidelines for local planners to use when creating their plans. Because of this, the plan assessment tool highlights a lot of missing information. It would not be reasonable for the authors to include all of this material in a plan that is not associated with a particular jurisdiction; however, it would be helpful if it had been mentioned, so that planners using these guidelines would recognize that the need to include the pertinent information in their plans.

7.2 Layout assessment

Considering all the decisions that must go into a plan, it is easy to dismiss the task of laying out individual sites as a minute detail, and simply specify what stations should be set up and how many staff members will work at each. However, the layout of a POD can strongly influence both its performance and the quality of the resident experience. Since every POD is designed for use in a different facility and includes different stations, the design process is qualitative, and difficult to automate or optimize. We needed a way to assess layout designs, in order to guide planners through the process of creating an efficient POD layout.

7.2.1 Layout assessment details

Using general queueing design knowledge (Hall, 1991) and observations made during time studies of POD exercises, I expanded these categories into a three-page worksheet for planners. Emergency planners at Montgomery County reviewed the worksheet, and I revised it in accordance with their questions and suggestions. After using it to evaluate several plans, I further updated it to address other usability issues. The worksheet groups guidelines into four categories: clinic layout, staff comfort, resident comfort, and workstation layout; the complete assessment tool is included in Appendix B.

Clinic layout

Guidelines for the overall layout of the POD include the following: Use separate entrances and exits to avoid opposing flows through a single doorway. Triage residents outside the POD. Separate residents with symptoms and residents who report contact with a disease agent for evaluation. Protect residents waiting outside from the weather. Clearly denote the location and identity of all stations and queues. Place easy-to-understand signs where residents can see them as they move through the POD. If residents must watch an educational video, provide quiet rooms for them to watch it in; where possible, use several small rooms rather than one large room.

Staff comfort

The guidelines for staff comfort include the following: Place materials efficiently at workstations to make service consistent and comfortable. Provide a separate entrance for staff away from the client arrivals. Designate a break room for staff to use during their scheduled breaks, away from the main flow of the POD.

Resident comfort

The guidelines for resident comfort include the following: Assign floating staff to assist residents who have questions. Provide separate stations for residents with special needs, such as translators or mobility aides. Make sure that residents who need to fill out forms are provided with a way of doing so – pens and either clipboards or tables and chairs.

Workstation layout

The guidelines for workstation layout include the following: Provide sufficient space for queues to form, based on the predictions of the clinic planning models discussed in Chapter 4. Ensure that available staff will be visible from the head of the queue, and provide line directors to guide clients. To reduce server idle time, stage the first client in the queue near a server, so that when the server becomes available the client only has a few steps to take. Use flow-through layouts for all workstations to prevent clients' paths crossing as they move in opposite directions.

7.2.2 Evaluation of sample layouts

To test the layout assessment tool, I obtained several sample clinic layouts. I used the worksheet to evaluate them, and compared the results with feedback that the planners received after using the layouts for large-scale exercises. The layouts discussed here came from Seattle-King County, Washington and Oklahoma City-County, Oklahoma, and are included in Appendix D, along with completed assessment worksheets for each.

Seattle-King County Community Center Layout

The Seattle-King County Health Department has developed a generic POD layout that can be used in any location with a single large room; they also created a layout that fits into the floorplan of a community center with two adjoining, full-sized gymnasiums. I chose the community center layout to evaluate, since feedback was available from an exercise held there during the fall of 2005. Both layouts include registration and dispensing, with floating medical counselors and triage outside the building.

This design incorporates proper unidirectional flow; residents enter from one end of the building and depart from the other. The triage component appears to be lacking in detail; there is a symbol marked for "EMT/Medical Evaluation" outside the building, but no information regarding who would direct residents there or where they would go afterwards. No provision is shown for residents waiting outside the clinic. The plan associated with this layout does not call for residents to watch an educational video. The layout positions line directors at key points throughout the POD, and allocates space for support functions such as incident command, police command, and communications, along with the necessary first aid and materials storage areas.

The design also performs well in the areas of staff and resident comfort. A room is allocated for staff to take breaks in a part of the building where residents will not go, with its own set of entrances. Significant provisions are made for resident assistance; aides are located outside the entrance to help those with limited mobility, and the registration area has translators for the most common foreign languages.

Residents complete forms while standing at one of several tables, where health educators are located to assist them and answer any questions that might come up.

The layout for the registration station in this design is somewhat congested; six tables are set in two rows on one side of the main flow path, with four more tables on the other side of the room for residents requiring translation services or other assistance. Three out of four residents have to walk between the tables in the first row, and then return the same way after completing their paperwork; since there is no set flow pattern within the station, the narrow spaces between tables will easily become congested. The dispensing station is set up in a more efficient manner; personnel at the door check residents' forms and direct them to one of three groups of servers, based on the amount of attention they require. Each server group has a compact, snaking queue, which is set back to allow residents to see available servers easily. Individual servers are set several feet apart, so residents who have been served can pass through the station towards the exit without running into approaching residents. The only aspect that the assessment recommends for improvement in this area is staging residents in front of available servers.

Oklahoma City-County Health Department Mass Immunization / POD layout

The Oklahoma City-County Health Department also provided a generic POD layout, scaled to fit in a gymnasium floor. The layout includes three stations: registration, dispensing/vaccination (dependent on the agent involved), and exit counseling.

The overall layout of the POD is linear, with residents entering at one end of the room and exiting at the other. The plan associated with the layout is a nonmedical model; mass media channels would tell residents with symptoms or contact to report to other health care providers instead of PODs, so no triage station is required. Queueing outside the clinic does not appear to be expected, and there is no video for residents to watch. Space is set aside for storage and first aid, and support personnel work at tables set away from the main flow of the POD.

Provisions for staff comfort are not obvious in the creation of this layout; no break area is designated for staff, and the only entrances shown are those used by residents. By definition, these criteria imply multiple rooms, and the layout is designed to fit on the floor of a gymnasium; both the break room and the staff entrance would presumably be adjacent to the gymnasium, according to the design of the facility being used. The layout performs much better with regard to resident comfort; the exit counselors can answer any questions residents may have after treatment, and a separate lane is set aside for anyone who requires assistance completing the forms. No space is set aside for residents to fill forms unassisted, because residents will complete their forms while standing in line.

The POD design is very well thought-out with regard to station layout. Queueing space is allocated at each station; although sight angles are wider than is optimum, positioning two traffic monitors along each row of servers effectively reduces them. A dashed line denotes where residents will be staged while waiting for a server to become available. Turn-back service is used for dispensing, but residents are all traveling in the same direction before and after service, so this should not be a significant factor in causing congestion.

7.3 Discussion of assessment tools

Applying these assessment tools to the plans and layouts discussed above demonstrates their value to planners who have never had the experience of setting up a POD. Through the application of the assessment tool to these plans, I was able to discover and correct some of its flaws and weaknesses; I corrected several omissions, such as including first aid and material storage areas on the layout tool, and improved the general usability and appearance of both tools. Feedback from the planners in Montgomery County's health department was also essential, particularly to ensure that the terms used in the tools were consistent with current public health terminology.

Applying the layout assessment tool to the King County community center layout was particularly interesting, since it had been used for a mass vaccination exercise in November of 2005. After applying the layout assessment tool to the layout, I checked the after-action report from the exercise to find whether the tool's conclusions agreed with observations made by staff during debriefing. The two main improvements suggested by the layout assessment tool were to provide shelter for residents waiting outside and to implement staging at the dispensing station. Discussions with one of the planners revealed that shelter outdoors was called for in the plan, though not depicted on the layout; however, one suggestion staff members gave during the debriefing session was to provide seating for residents waiting outside. The planner also mentioned that congestion among the registration tables was not a significant factor; this suggests that the layout provided was not drawn to scale. The after-action report also mentioned that throughput was slightly below the target level; this may have been associated with arrival rates to the clinic, but it is also possible that the dispensing station was a bottleneck, and that staging would have reduced cycle time in the clinic.

The tools have been reviewed by experts and tested on real plans and layouts, and both their uses and their limitations have been shown. They are only assessment tools. They cannot write plans or draw layouts; their purpose is to evaluate documents once they have been created, to point out missing data, and to provide a guide for refining them. The plan assessment tool is not authoritative; planners who use the tool should also consult guidelines provided by state or federal authorities, which may require additional content or dictate certain portions of the plan. Both tools attempt to objectively assess the performance of a POD based on qualitative measures; following their guidelines should improve performance, but it is impossible to predict how much performance will change. Finally, applying the assessment tools is by no means a substitute for exercising POD plans; rather, they should be used before planning or running the exercise, in order to ensure that the exercise runs as smoothly as possible.

Chapter 8: Summary and conclusion

The overall goal of this research has been to provide public health emergency preparedness and response planners with tools that can help them do their jobs better. The tools that I have created will help planners to improve their estimates of POD performance measures; with this information, planners become better informed when they have to make decisions regarding staff placement, POD layout, and other relevant concerns.

8.1 Summary

In this research, the broad spectrum of types of queueing models was gathered and organized into a comprehensive set of equations that is useful for a range of general applications.

Where existing models failed to provide a good approximation for a certain type of system, I proposed adjustments that would expand their capabilities, and validated them using Arena simulation modeling software. This led to a modification of the standard approximation for batch queueing time with multiple servers. This equation is exact for a single server, and provides an upper bound in the case of multiple servers, where WIBT drops off as utilization decreases. I also suggested a new way of approximating WIBT for systems with several incoming batch streams of different sizes by creating an aggregate batch size. This estimator has shown excellent performance for a variety of incoming batch mixes.

I combined the queueing models that I had gathered to create a software framework in Microsoft Excel. This framework takes several user inputs and generates an analytical model of a system, using the queueing models to predict performance measures such as cycle time, queueing time, and server utilization at each station in the system. One limitation of this model is that it uses steady state approximations for the queueing system; however, this should not be a problem since it tends to overestimate rather than underestimate queueing times during the startup phase, and it is in the nature of emergency response planning to approach a situation from a pessimistic perspective. The software is designed with public health emergency response planners in mind, and includes such features as pre-configured stations based on the performance data we recorded during time studies.

While simulation models would provide planners with much of the same data, and a greater capacity to create models that match reality to very low levels of detail, they have their disadvantages. The software is expensive and requires significant training to become comfortable with, whereas planners can run the analytical models in Excel, which most of them already use regularly. Simulation models can also require extensive runtimes to attain a high level of confidence, while the dynamic calculations performed within analytical models allow planners to use them not only to create plans, but also to adjust their response during an event based on actual conditions.

I created the clinic planning model generating software so that planners would have a way of estimating the performance of a facility that had never been set up or used. In the same spirit, I created two more assessment tools that planners can use to evaluate the completeness of emergency response plans and the efficiency of POD layouts. The tools were refined based on testing with actual plans and layouts, along with feedback from public health professionals. Comparison with feedback from full-scale exercises has shown that the tools provide a useful assessment of these documents, and can be a valuable resource for planners whose experience with live exercises is limited.

8.2 Future directions for research

Several parts of this work reveal opportunities for further research to be performed in the future. Queueing models that maintain their accuracy even for systems with high SCVs must be created. Models of WIBT are needed that can more accurately represent the behavior of the system under low utilization; I have suggested an approach for this, but a closed-form approximation needs to be developed, and the approach must be validated for generalized arrival processes. In the context of modeling PODs, questions remain about the behavior of families or other groups that travel through the POD together; it may be possible to model this phenomenon as a series of move batches and process batches. Another concern among planners is, given a limited number of available staff, how best to distribute them among the stations of a POD. In its current form, the model can aid planners in determining the distribution via heuristics and brute force, but automating the search would be a welcome feature.

An ongoing effort is in place to enhance the interface of the model-generating software in response to feedback from planners at Montgomery County and other jurisdictions around the country. I have refined the assessment tools, based on my own experience in applying it and on comments from planners; in the future, as more people apply the assessments to their own plans and layouts and give feedback, further changes will most likely become necessary.

Appendix A: Software user guide

CLINIC PLANNING
MODEL GENERATOR

USER'S GUIDE
Version 1.24

December 20, 2005
Institute for Systems Research
University of Maryland

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Table of Contents

Introduction

The Clinic Planning Model Generator is intended to grant public health officials the ability to quickly create an accurate model that will provide immediate assistance with planning for a treatment campaign. The model can be used either in the advance planning stages of a campaign or for support during an active effort. In general this program is designed to assist in planning a clinic with improved efficiency and performance while enlightening the planners on what to expect in the event of an outbreak.

This interactive software model allows clinic planners to enter known population information and set time constraints specific to their application. Immediate results show suggested staff levels and detailed clinic information regarding waiting times, queue lengths, and cycle time. Adjustments can easily be made to staffing levels and other inputs until the user is satisfied with the efficiency of the clinic. The versatility of this program allows the user to accept default values if little information is known about their clinic, or input more detailed information such as routing probabilities and process times. Since the clinic models operate entirely in the Microsoft Excel environment, some familiarity with this package is helpful. In order to run the model, two files are needed: "Clinic Generator 1.24.xls" and "Clinic Template.xls." These two files must be placed in the same folder for the program to work.

This user guide includes details on creating clinic models with the Clinic Planning Model Generator, and discusses how to use the models once created. At each step, examples will be given pertaining to a small, fairly simple clinic; the Excel file for this model, "Sample Clinic.xls," is included in the installation package.

In 2004, Public Health Services of the Montgomery County, Maryland Department of Health and Human Services became one of the first eleven public health agencies in the nation to be recognized as Public Health Ready by the National Association of County and City Health Officials (NACCHO) and the Centers for Disease Control and Prevention (CDC) of the U.S. Department of Health and Human Services. The county is home to one of eight Advanced Practice Centers (APCs) for Public Health Preparedness funded by NACCHO through the CDC.

Important Terms

1. Cycle Time – the average time that a patient spends at a station. It includes queue time and process time. The total cycle time is the total time a patient is expected to be in the clinic.
2. Interarrival Time – the average time between patients arriving. In the case of bus interarrival time, this is the average time between two buses arriving with patients.
3. Process Time (Service Time, t_o) – the average time that a staff member is in contact with a patient at a station.
4. Queue Length – the average number of patients waiting in line at a station.
5. Queue Time (Wait Time) – the average time that a patient waits in line at a station.
6. Routing Probability – the probability that a patient at one station will visit that station when they leave. Example: If five percent of patients who leave Reception go to Sick Bay, and the remaining ninety-five percent go to Education then the routing probability from Reception to Sick Bay equals 0.05, and the routing probability from Reception to Education is 0.95.
7. Utilization – the fraction of available station capacity being used.
8. Variance (σ_o) – the variance of the processing time at a station.
9. Work in Process (WIP) – the average number of people at a station. This includes patients waiting and patients being serviced.

Creating a Clinic Planning Model

Preparation

Before beginning to build the clinic planning model, it's helpful to gather all the information that will be used, as well as planning out the overall structure of the clinic. Worksheets are provided in Appendix A to help with this task; complete them before proceeding to the next section. A completed worksheet with the details of our example clinic is included below. Note that the listed stations are numbered so that the associated destinations are all later in the order. Since the model does not allow patients to travel backwards, the stations need to be listed in an order that permits the desired routings. Look at the sample model for an example of how the table should be used. By doing this, we ensure that we can easily fill in the appropriate probabilities for patient movement on the second sheet. Note that Appendix A contains two versions of the second worksheet: one with dashed lines for black and white printing, and one with colored lines.

Clinic Planning Model Generator
Clinic Planning Worksheet

This worksheet is designed to help you prepare to use the Clinic Model Generator tool. The series of questions below will guide you in gathering the necessary information to build a clinic model.

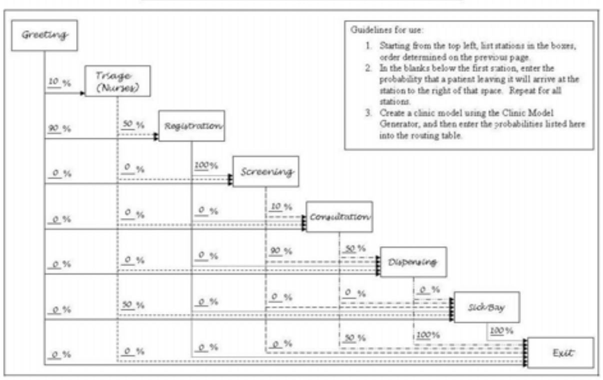
Demand data

What is the size of the population to be treated in the clinics? 50,000
How many days have been allotted for treatment? 10
How many hours will the clinics be open each day? 16 (2 shifts)
How many clinic sites will be opened for treatment? 10

Station data

In the "Station Name" column of the table below, list all stations that patients might visit as they pass through the clinic. In the "Possible destinations" column, make a note of the stations that patients might visit after that station. Since the model only allows for forward travel, the stations need to be listed in an order that permits the desired routings. Use the column labeled "#" to note the correct order for the stations; look at the sample model for an example of how the table should be used.

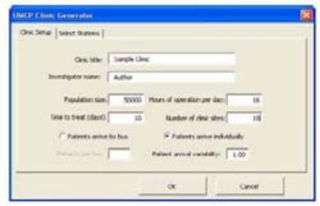
Station Name	Possible destinations	#
Greeter	Triage, Registration	1
Triage (Nurses)	Registration, sick-bay	2
Sick-bay	Exit	7
Screening	Consultation, Dispensing	4
Consultation	Dispensing, Exit	5
Dispensing	Exit	6
Registration	Screening	3



Clinic Setup

Step 1: Open the *Clinic Generator 1.24.xls* file (If a Security Warning appears, select 'Enable macros'; they are required for this software to function correctly). The clinic setup dialog (right) will appear. The dialog can also be called up by pressing the button labeled "Create Clinic Model".

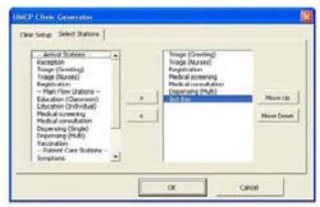
Make the appropriate entries and selections for your clinic in the "Clinic Setup" tab, then move to the "Select Stations" tab. In the picture at right, we've entered the sample clinic data from our worksheet.



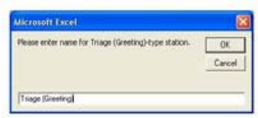
Step 2: Select the stations required for your clinic from the list on the left, using the right arrow button to add them to the list of selected stations. Double-clicking a station will also add it to the list.

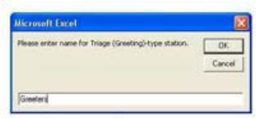
You can use more than one of the same type of station – for instance, if you have two separate paths for patients, both of which include a registration or dispensing station. A detailed list of the default station types follows on the next page.

The order of stations in the list can also be changed, using the "Move Up" and "Move Down" buttons.



Step 3: When the initial clinic parameters are set to your satisfaction, hit the "OK" button to create the clinic. You will be asked to choose a location to save the clinic model. Next, the program will ask you to enter names for all your stations. The default names will work, but if you have multiple stations of the same type, this is when you should assign them distinctive names (for instance, in the picture at right, we've renamed the default "Triage (Greeting)" to the "Greeters" we used in the worksheet). Certain station types will also ask for extra information, such as the classroom size for a classroom education station.





When you have entered all the necessary data, the spreadsheet model will be generated and saved.

Step 4: After naming all the stations, you will be required to enter information about where patients go when they depart each station.

The Routing Table is used to determine what path a patient will take through the clinic. For example, in a disease outbreak situation, some small percentage of patients will be identified as symptomatic, and routed away from the main clinic path.

Routing Probabilities

From Greeters	From Triage (Nurses)	From Registration	From Medical screening	From Medical consultation	From Dispensing (Multi)	From Sick Bay	
100.0%							To Triage (Nurses)
0.0%	100.0%						To Registration
0.0%	0.0%	100.0%					To Medical screening
0.0%	0.0%	0.0%	100.0%				To Medical consultation
0.0%	0.0%	0.0%	0.0%	100.0%			To Dispensing (Multi)
0.0%	0.0%	0.0%	0.0%	0.0%	100.0%		To Sick Bay
0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	To Exit
100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	Sum

Sum should be 100%

The table lists departure stations across the top, and arrival stations down the right side. The cells denote the percentage of patients departing from a station that will arrive at another station; a probability of 0% indicates that patients cannot make that particular trip. For instance, using the values shown above, every patient who leaves the greeters (100%) will proceed to the Triage (Nurses) station, and from there to the Registration, Medical screening, Medical consultation, Dispensing, and Sick Bay stations before they reach the exit. This is the default routing specified at model creation, and it should be modified by the user if the patient paths are less straightforward. The cells in the upper right corner of the table are shaded grey because the model does not allow patients to move backwards through the clinic.

Routing Probabilities

From Greeters	From Triage (Nurses)	From Registration	From Medical screening	From Medical consultation	From Dispensing (Multi)	From Sick Bay	
10.0%							To Triage (Nurses)
90.0%	50.0%						To Registration
0.0%	0.0%	100.0%					To Medical screening
0.0%	0.0%	0.0%	10.0%				To Medical consultation
0.0%	0.0%	0.0%	90.0%	50.0%			To Dispensing (Multi)
0.0%	50.0%	0.0%	0.0%	0.0%	0.0%		To Sick Bay
0.0%	0.0%	0.0%	0.0%	50.0%	100.0%	100.0%	To Exit
100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	Sum

Sum should be 100%

In this example (which contains more likely routings but is still fairly simplistic), only 10% of patients are identified as having potential problems and sent to from Greeters to Triage(Nurses), while the other 90% proceed to registration. From the nurses' station, 50% of the patients turn out to be healthy, and follow the others to registration. The other 50% go to sick bay for treatment. After filling out their forms at registration, the remaining patients have their forms checked at the medical screening station. While 10% have contraindictions or other reasons to have a consultation with a doctor, the other 90% are cleared to get their medication and go home. Of the patients who have a consultation, half receive medication and half go home. After treatment in the sick bay, all remaining patients leave the clinic, either to go home or to be taken to the hospital. Note that the sums in the bottom row are all 100%. If the patients departing from a station aren't all accounted for, this value will turn red to indicate an error.

After entering the appropriate values from the corresponding entries in the routing worksheet, click the 'Continue…' button to finish building the clinic planning model.

Default Station Types

Several commonly used clinic stations are included in this program. Each is associated with a processing time mean and variance, which will be added to the clinic model automatically. These times will not describe every possible clinic with perfect accuracy; they depend heavily on various factors, such as the familiarity clinic workers have with their jobs, the length of forms which must be filled by patients, and the type of medication being dispensed or vaccination being applied. The pre-defined parameters for each process can be modified if data is available describing the specific type of operation in question; otherwise, the default values will serve as guidelines.

The table below lists the included stations and the processes they are intended to model. Many of the stations listed have overlapping functions, appropriate for various types of clinic; only the ones appropriate for modeling your particular clinic should be used.

Station Type	Description
Arrival Stations	
Reception	Patients arrive at this station with a set of forms filled out at a Pre-POD; their answers are checked and then they are sent to the appropriate subsequent station.
Triage (Greeting)	Patients are greeted as they arrive at the clinic; those identified as needing special care (special needs populations), contact with an infectious agent, or showing symptoms of an illness are diverted to the appropriate stations.
Triage (Nurses)	Patients flagged as showing potential symptoms are examined and either return to the main patient path or receive appropriate treatment.
Registration	Patients receive forms and instructions on filling them out.
Main Flow Stations	
Education (Classroom)	Patients are shown an educational video for purposes of informed consent; this station includes an added parameter defining the number of seats in each classroom.
Education (Individual)	Patients who have questions can be directed to this station to receive further information.
Medical screening	Patients' forms are examined to make sure they can safely receive the treatment in question; those with potential complications are referred to an expert for a consultation.
Medical consultation	Patients with possible complications have an interview with an expert to determine whether they should be treated, and how.
Dispensing (Single)	This station dispenses the same medication to every patient.
Dispensing (Multi)	This station has several medications available, and usually

	follows consultation for patients who cannot take the standard medication.
Vaccination	The times for this station are based on a vaccine that requires three separate injections.
Flu Vaccination (Adult)	The times for this station are based on observations of a nurse vaccinating only individual, healthy adults (rather than children or family groups).
Flu Vaccination (Children)	The times for this station are based on observations of a nurse vaccinating only children and their parents.
Flu Vaccination (All Ages)	The times for this station are based on the combined observations of the two previous groups and can be used for stations where families with children are not treated separately.
Patient Care Stations	
Symptoms	Patients showing symptoms consistent with the disease being treated are brought to a holding room for medical examination, after which they are allowed to re-enter the main clinic flow, or sent to a primary care facility.
Contact	Patients who know they have been in contact with the agent being treated for are held for medical examination, after which they are allowed to re-enter the main clinic flow, or sent to a primary care facility.
Sick Bay	Patients who develop symptoms after passing the initial triage area are sent here for medical examination, after which they are allowed to re-enter the main clinic flow, or sent to a primary care facility.
Mental Health	Patients who become overly anxious or disruptive can be brought here to receive care from mental health professionals or crisis counselors.
Custom Station	
Custom	If a custom station is selected, the user will be asked to provide data for process time mean and variance.

Working with a Clinic Planning Model

Clinic Planning Model Pages: Table of Contents

When the clinic planning model is created or opened, the startup screen contains title and author information, and a link to the table of contents. Below is a list of the entries in the table of contents; more detailed explanations of each page follow. The same navigation buttons are used throughout the model.

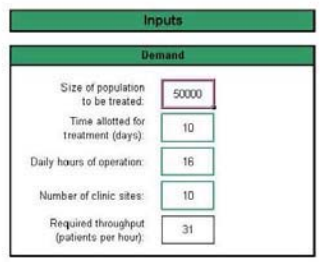
Main	This page is the most important part of the interface, where demand and staffing values are set, and where the resulting clinic statistics can be seen.
Model Parameters	The Model Parameters page contains values that govern station operations, including arrival type and average process time and variance.
Routing Table	The routing table on this page is used to set the percentage of people who visit each station. A distance table is also included, which is used to calculate the time patients spend walking from one station to another.
Staffing	The main portion of the model allows you to dynamically configure the service staff at each station, but many other personnel are required for the operation of a clinic. The Staffing page tallies the support staff to provide an accurate estimate of total clinic staff. Security personnel are not included in the staffing estimate.
Report	This page gives a simple, printable summary of the clinic's performance, including graphs comparing the performance of individual stations.
Author Credits	The Author Credits simply names the main authors of the Clinic Model Generator program, along with several significant contributors
Startup Screen	The Startup Screen button returns the user to the initial screen of the model, which gives the clinic's name and creator.

Clinic Model Pages: Main

The main page of the clinic planning model contains a lot of information, so we'll go through it step by step according to the numbers above.

Step 1: Input Demand

After you create a model with the generator program, the numbers you input for the population demands and clinic operations will appear here. To investigate alternative scenarios, such as the effect of changing the number of clinic hours or length of a treatment campaign, change the values in the green-edged boxes.

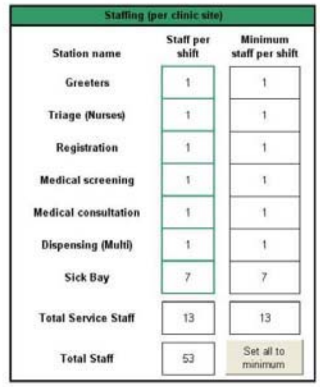


The *required throughput* is the number of patients that must be processed by the clinic every hour in order to treat the given population in the allotted time.

Note: The model assumes that the population will be equally distributed among the chosen number of clinic sites. If this is not appropriate for your region, each clinic should be evaluated individually, with the appropriate population size and with a single clinic site.

Step 2: Input Staffing

Based on the patient flow requirements and the performance of the stations you selected in the model creation dialog, a minimum staffing level for each station has been determined. This value is shown in the right-hand column of black-edged boxes. To the left is the staffing level that will actually be used; this is set to the minimum value at model creation.



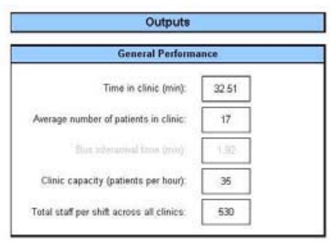
It is often useful to add more staff to a station that is not performing as well as it might. As in the input demand area, green-edged boxes indicate a user-input value. If the user-selected value for a station is below the minimum value, it will be highlighted in red. This must be corrected in order for the model to function correctly; while below-minimum values are selected, outputs will give errors or negative values.

The button in this area, labeled "Set all to minimum," allows the user to automatically update all staffing values if the calculated minimum changes (for instance, because of updates to routing values or population size).

Station service staff are totaled below each column; below that, the total staff, including team leaders and administrators (see Staffing page), is given.

Step 3: General Performance

This area gives overall performance measures for the clinic; all of these values are calculated dynamically, and will update automatically when you change any input value.



- Time in clinic: the total time that, on average, each patient will spend in the clinic, including wait time, treatment time, and walking time.
- Average number of patients in clinic: the total number of patients in queue and being serviced at all stations.
- Bus interarrival time: if patients arrive at the clinic by bus (bus sizes are set on the Parameters page), this gives the necessary arrival frequency to support the specified

patient flow. If individual arrival has been selected, this box will be grayed out.

- Clinic capacity: the number of patients the slowest station in the clinic (known as the bottleneck station) is capable of processing per hour. This should be larger than the required throughput in the input demands section.
- Total staff per shift across all clinics: This total number of staff includes support and service staff for each clinic in the model, but does not take into account incident command staff.

Step 4: Station-level Results

This part of the page gives more detailed information about individual stations, including averages for wait time, length of queue (the number of people waiting at a station), and utilization (the proportion of the time that servers are not idle).

For each of these three columns, the station with the highest value will be highlighted in red. This is intended to call attention to the station *most likely* to need improvement; however, no matter how efficient the clinic is, there will *always* be stations with the longest wait time, longest queue, and highest utilization.

Station-level Results

Station name	Wait time (min)	Queue length	Utilization
Greeters	0.04	0	13.5%
Triage (Nurses)	0.13	0	9.1%
Registration	1.08	1	57.1%
Medical screening	7.59	4	86.7%
Medical consultation	0.55	0	18.6%
Dispensing (Multi)	1.09	1	63.0%
Sick Bay	6.64	3	90.0%

Clinic Model Pages: Model Parameters

The Model Parameters page contains data describing patient arrivals to the clinic and operations at each station. *With the exception of group size, these values should not be altered unless you have your own data to replace them with.*

- Group size: if value is greater than 1, this is the number of patients per bus arriving at the clinic. Setting the value to 1 indicates that patients will arrive individually.
- Variability: for individual arrivals, this determines the regularity of the arrival process. A variability of 1 indicates moderately variable arrivals; values close to 0 mean that patients arrive like clockwork, while values greater than 1 suggest that patients arrive in very irregular spurts.
- Average walk speed: this walking speed is used to calculate the time patients spend walking from one station to the next. It should not be changed unless the user has data indicating a more accurate value.
- Station processing time: this is the average time required to complete a station process. Default values come from data recorded at exercises in Montgomery County, Maryland, and Burlington County, New Jersey.
- Station variance: the variance in a station's processing times.

Arrival:	
Group size (1 for individual):	1
Variability (Individual):	1
Average walk speed (ft/s):	4.05
Station 1:	**Greeters**
Processing time (min):	0.259
Variance (min^2):	0.07
Station 2:	**Triage (Nurses)**
Processing time (min):	1.752
Variance (min^2):	1.6104
Station 3:	**Registration**
Processing time (min):	1.154
Variance (min^2):	0.5329
Station 4:	**Medical screening**
Processing time (min):	1.752
Variance (min^2):	1.6104
Station 5:	**Medical consultation**
Processing time (min):	3.765
Variance (min^2):	4.3732
Station 6:	**Dispensing (Multi)**
Processing time (min):	1.34
Variance (min^2):	0.5408
Station 7:	**Sick Bay**
Processing time (min):	12.698
Variance (min^2):	75.3647

Clinic Model Pages: Routing Table

The Routing Table is used to describe the paths that patients will take through the clinic. For example, in a disease outbreak situation, some small percentage of patients will be identified as symptomatic, and routed away from the main clinic path. The default routing specified at model creation is linear; all patients move through every station in the clinic in order. This should be modified by the user if the patient paths are less straightforward. The cells in the upper right corner of the table are shaded grey because the model does not allow patients to move backwards through the clinic.

Note: if the number of stations in the model makes it difficult to see everything at once, you can zoom out to view more of the table. Alternatively, you can select the first of the 'To' stations on the right and click on 'Window – Split'. This will allow you to scroll the main part of the table while the top and right labels remain visible.

Routing Probabilities

From Greeters	From Triage (Nurses)	From Registration	From Medical screening	From Medical consultation	From Dispensing (Multi)	From Sick Bay	
10.0%							To Triage (Nurses)
90.0%	50.0%						To Registration
0.0%	0.0%	100.0%					To Medical screening
0.0%	0.0%	0.0%	10.0%				To Medical consultation
0.0%	0.0%	0.0%	90.0%	50.0%			To Dispensing (Multi)
0.0%	50.0%	0.0%	0.0%	0.0%	0.0%		To Sick Bay
0.0%	0.0%	0.0%	0.0%	50.0%	100.0%	100.0%	To Exit
100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	Sum

Sum should be 100%

The table lists departure stations across the top, and arrival stations down the right side. The cells denote the percentage of patients departing from a station that will arrive at another station; a probability of 0% indicates that patients cannot make that particular trip. For instance, using the values shown above, upon leaving the Greeter station, 10% of patients will be sent to Triage (Nurses), while the rest will proceed to Registration.

Note that the sums in the bottom row are all 100%. If the patients departing from a station aren't all accounted for, this value will turn red to indicate an error.

Distance Table (in ft)

From Greeters	From Triage (Nurses)	From Registration	From Medical screening	From Medical consultation	From Dispensing (Multi)	From Sick Bay	
0.00							To Triage (Nurses)
0.00	0.00						To Registration
0.00	0.00	0.00					To Medical screening
0.00	0.00	0.00	0.00				To Medical consultation
0.00	0.00	0.00	0.00	0.00			To Dispensing (Multi)
0.00	0.00	0.00	0.00	0.00	0.00		To Sick Bay
0.00	0.00	0.00	0.00	0.00	0.00	0.00	To Exit

The Distance Table on the same page works similarly. Here, the distance from each station to the next is specified, in order to incorporate walking times into the model. By default, all distances are zero, so that walking time is ignored. When assigning distances, it is only necessary to fill in values for possible combinations. For instance, in the previous example, no patients go from registration to the exit, so there is no need to assign a distance to this route.

Clinic Model Pages: Staffing

Position	Staff	Total
Clinic Manager	2	53
Medical Records	10	
Supply Manager	2	
Clinic flow / forms helpers	8	
Translators	4	
Traffic flow	2	
Float staff	3	
EMT	1	
IT Support	1	
Greeters Leader	1	
Greeters Staff	1	
Triage (Nurses) Leader	1	
Triage (Nurses) Staff	1	
Registration Leader	1	
Registration Staff	1	
Medical screening Leader	1	
Medical screening Staff	1	
Medical consultation Leader	1	
Medical consultation Staff	1	
Dispensing (Multi) Leader	1	
Dispensing (Multi) Staff	1	
Sick Bay Leader	1	
Sick Bay Staff	7	

This page allows the model to estimate the various support staff required to run a clinic; the default values come from Annex 3 of the CDC's Smallpox Vaccination Clinic Guide. The numbers for each support position, highlighted with green borders, can be adjusted by the user, but service staff at each station can only be changed on the Main page. A team leader is also provided for each station. The total of the staff specified here is the number seen at the bottom of the Main page and used to calculate staffing across all clinics. Incident command and security personnel are not included in this estimate.

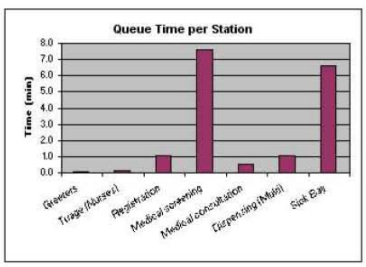
Clinic Model Pages: Report

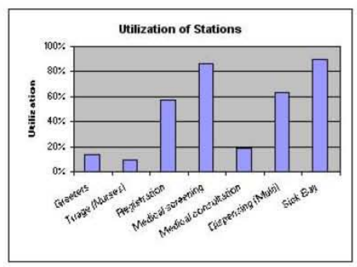
A printable summary of the clinic can be found on the Report page. It lists the clinic demand information, along with the overall clinic performance data and a breakdown of each station. Additional station details are included in this table, such as the physical queuing space required and station cycle time. Two bar charts are also provided; these allow easy comparison of station queue time and utilization.

Sample Clinic 9/14/2005
Model created by Author with Clinic Planning Model Generator 1.21

Size of population to be treated:	50000	Time in clinic (min):	32.51
Time allotted for treatment (days):	10	Average number of patients in clinic:	16.93
Daily hours of operation:	16	Bus interarrival time (min):	1.92
Number of clinic sites:	10	Clinic capacity (patients per hour):	34.73
Required throughput (patients per hour):	31	Total staff per shift across all clinics:	530.00

Station	Staff	Utilization	Process Time (min)	Wait Time (min)	Cycle Time (min)	Queue Length	Required Queue Space (ft)	WIP
Greeters	1	13%	0.26	0.04	0.30	0	0	0
Triage (Nurses)	1	9%	1.75	0.13	1.89	0	0	0
Registration	1	57%	1.15	1.08	2.23	1	2	1
Medical screening	1	87%	1.75	7.59	9.34	4	11	5
Medical consultation	1	19%	3.77	0.55	4.31	0	0	0
Dispensing (Multi)	1	63%	1.34	1.09	2.43	1	2	1
Sick Bay	7	90%	12.70	6.64	19.34	3	10	10
Total	**13**							





Creating variations on a clinic model

Sometimes in the process of creating a clinic model, it may become necessary to go back and change the order of the stations in the model, or to add or remove stations. To simplify this process, the Clinic Planning Model Generator includes a feature allowing the user to import data from an existing source model into the setup for a new model. To use this feature, run "Clinic Generator 1.24.xls", cancel the setup dialog that appears, and click on the "Import Data to New Model" button.

When you have selected a model file to import from, the clinic setup dialog will appear; all the fields should already be filled with the information used to set up the source model. On the Stations tab, you will see a list of the stations that were part of the source model. The list can be manipulated by adding, removing, and repositioning stations, just like during the initial model setup. All of the data associated with these stations in the source model, including names, process times, and variances, is included with the stations in this list; however, if you remove the station from the list, the data can only be recovered by going back to the source model.

Once the station list is arranged to your satisfaction, click on the "OK" button to create the clinic. Please be aware that the default filename for the new model will be the same as the default filename for the source model. If you do not wish to overwrite the source model, select a new filename.

Note: Routing data cannot be imported from source models, as the routing tables will be different based on the new set of stations in the model.

Additional Information

For information about how the model calculates these results, see the report "Technical Description: Mass Vaccination Clinic Spreadsheet Model," by Mark Treadwell and Jeffrey Herrmann.

If you have questions or suggestions, please contact Mark Treadwell at the following address:

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College Park, MD 20742-3035

Phone: 301-405-6572
Email: mtread@umd.edu

Appendix A:

Clinic Planning Worksheets

Cooperative Agreement Number U50/CCU302718 from the CDC to NACCHO supported this publication. Its contents are solely the responsibility of the University of Maryland and the Advanced Practice Center for Public Health Emergency Preparedness and Response of Montgomery County, Maryland, and do not necessarily represent the official views of CDC or NACCHO.

Clinic Planning Model Generator

Clinic Planning Worksheet

This worksheet is designed to help you prepare to use the Clinic Model Generator tool. The series of questions below will guide you in gathering the necessary information to build a clinic model.

Demand data

What is the size of the population to be treated in the clinics? __________

How many days have been allotted for treatment? __________________

How many hours will the clinics be open each day? _________________

How many clinic sites will be opened for treatment? _________________

Station data

In the 'Station Name' column of the table below, list all stations that patients might visit as they pass through the clinic. In the 'Possible destinations' column, make a note of the stations that patients might visit after that station. Since the model only allows for forward travel, the stations need to be listed in an order that permits the desired routings. Use the column labeled '#' to note the correct order for the stations; look at the sample model for an example of how the table should be used.

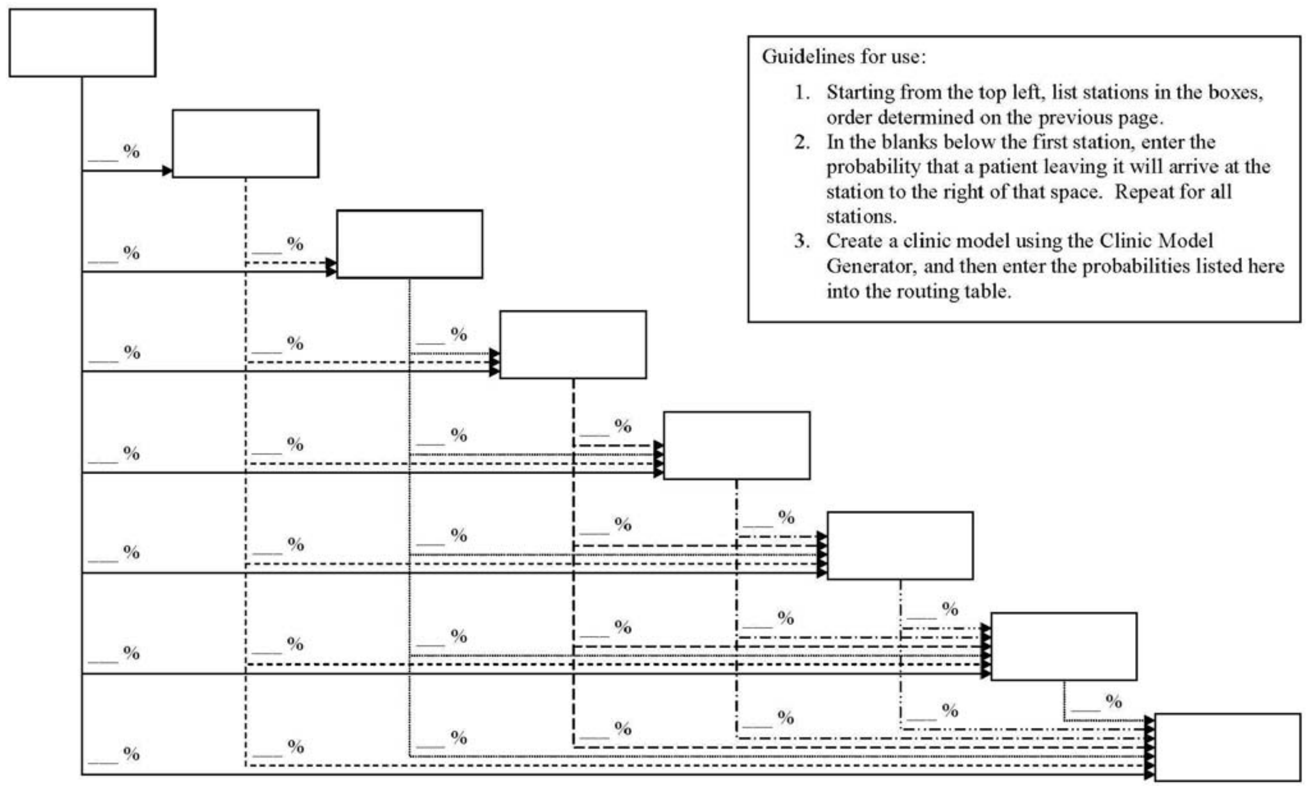
Station Name	Possible destinations	#

Appendix A: Clinic Planning Worksheets

Clinic Planning Model Generator
Clinic Routing Worksheet

Guidelines for use:

1. Starting from the top left, list stations in the boxes, order determined on the previous page.
2. In the blanks below the first station, enter the probability that a patient leaving it will arrive at the station to the right of that space. Repeat for all stations.
3. Create a clinic model using the Clinic Model Generator, and then enter the probabilities listed here into the routing table.

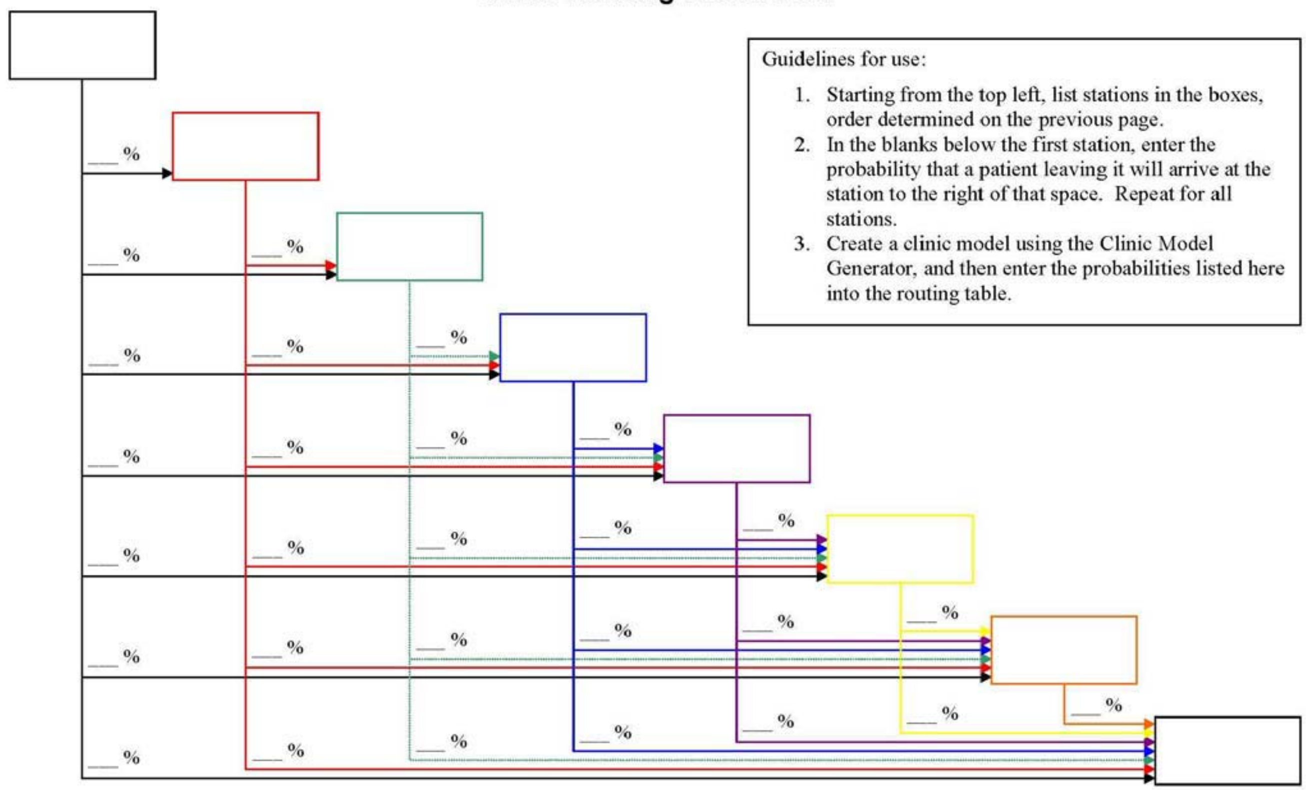


Appendix A: Clinic Planning Worksheets

Clinic Planning Model Generator
Clinic Routing Worksheet

Guidelines for use:

1. Starting from the top left, list stations in the boxes, order determined on the previous page.
2. In the blanks below the first station, enter the probability that a patient leaving it will arrive at the station to the right of that space. Repeat for all stations.
3. Create a clinic model using the Clinic Model Generator, and then enter the probabilities listed here into the routing table.



Appendix A: Clinic Planning Worksheets

Appendix B: Assessment tools

Layout title: ______________________________

Evaluator name: ____________________________

Assessment date: __________ / ____ / ________

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POD Plan Assessment Worksheet

This worksheet is designed to help you evaluate the completeness and performance of a single point of dispensing (POD) plan. A worksheet should be completed for each contingency being planned for. For each item on the worksheet, rate your layout plan according to the following scale:

- Complete. The item is included, along with all relevant details.
- Incomplete. The item is included, but some details are not given.
- Missing. The item is not included in the layout.
- Not applicable (N/A). The operational plan for the DVC makes this item unnecessary.

The ideal POD plan will specify the preparatory steps that should be completed and refreshed regularly before an event occurs as well as the procedures and personnel that are necessary to respond to a biological event.

Plan basics				
Does the plan include…	Complete	Incomplete	Missing	N/A
…the scope of events covered by the plan? *The plan should define the response for a specific size and type of event.*	☐	☐	☐	☐
…the number of people who must be treated?	☐	☐	☐	☐
…the timeframe allowed for treatment?	☐	☐	☐	☐
…a list of stations in the POD and their descriptions? *The stations in a POD should be applicable to all POD sites.*	☐	☐	☐	☐
…a flowchart of resident movement through the POD? *This flowchart describes the order in which residents may pass through stations and all possible routings.*	☐	☐	☐	☐
…designation of party responsible for maintaining or activating each component of the plan?	☐	☐	☐	☐
…compliance with NIMS command structure?	☐	☐	☐	☐
…agreements with neighboring municipalities? *The NCR matrix (available at www.montgomerycounty.gov/apc) lists several areas where agreements may be helpful.*	☐	☐	☐	☐

Facilities and supplies				
Does the plan include…	Complete	Incomplete	Missing	N/A
…identification of a command center?	☐	☐	☐	☐
…identification of a secure storage facility with backup power where vaccines can be stored? *A memorandum of understanding should be obtained for this site.*	☐	☐	☐	☐
...a list of approved POD sites, including maps? *"Approved" means a site has been surveyed, it meets the CDC's site requirements, and whoever controls it has agreed to its use as a POD (generally in a memorandum of understanding).*	☐	☐	☐	☐
…names and contact info for staff liaisons for POD sites? *This person will be notified when the site is needed for a POD.*	☐	☐	☐	☐
…procedures for disposing of waste from POD sites?	☐	☐	☐	☐
…physical layouts for each POD site? *The POD Layout Assessment Worksheet offers guidelines for creating efficient layout designs.*	☐	☐	☐	☐
…the locations of all supplies required for POD sites?	☐	☐	☐	☐
…a way of getting supplies and equipment to POD sites?	☐	☐	☐	☐
…procedures for staff to be transported to the POD sites?	☐	☐	☐	☐
…literature and forms which can be reproduced for distribution?	☐	☐	☐	☐
…clear denotations of where each station and queue is located? *Stations should be clearly marked with signs; queueing space can be designated by stanchions, tape markings, or other similar means.*	☐	☐	☐	☐
…simple, highly visible signs telling residents where they should be going next? *Signs should display a single word or phrase, in multiple languages where appropriate, along with an arrow; they should be located for maximum visibility (for example, taped above head height on a wall, or hanging from a ceiling).* *Crowd control stanchions or lines marked on the floor are also useful in directing resident traffic.*	☐	☐	☐	☐

Resident notification and treatment				
Does the plan include…	Complete	Incomplete	Missing	N/A
…procedures for alerting the public of a threat and the proposed response?	☐	☐	☐	☐
…a scheme for designating treatment sites and times for residents? *CDC guidelines offer examples of grouping residents by zip code or social security number.*	☐	☐	☐	☐
…agreements with local media for coverage and production of public service announcements? *A memorandum of understanding should be obtained.*	☐	☐	☐	☐
…details for the activation and staffing of a telephone hotline? *This hotline will be the point of contact for citizens with questions about response and treatment plans.*	☐	☐	☐	☐
…a designated method of resident transport to POD sites? *This may include residents within a certain radius traveling on foot; if residents will drive to the PODs, sufficient parking must be made available.*	☐	☐	☐	☐
…provisions for treatment of disabled residents, either by accessible POD sites or mobile treatment options?	☐	☐	☐	☐

Personnel				
Does the plan include…	Complete	Incomplete	Missing	N/A
…exercises and other training for POD staff?	☐	☐	☐	☐
…provisions for treating first responders? *Medication should be pre-positioned with first responders, for immediate use when the order is given.*	☐	☐	☐	☐
…the number of personnel (with and without medical training) required to staff PODs? *This number can be estimated using a Clinic Planning Model.*	☐	☐	☐	☐
… role description sheets for all personnel?	☐	☐	☐	☐
…identification of security personnel for POD sites? *Security may be provided by police or normal site staff.*	☐	☐	☐	☐

Layout title: _________________________

Evaluator name: _____________________

Assessment date: _______ / ___ / _______

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POD Layout Assessment Worksheet

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- Complete. The item is included, along with all relevant details.
- Incomplete. The item is included, but some details are not given.
- Missing. The item is not included in the layout.
- Not applicable (N/A). The operational plan for the POD makes this item unnecessary.

The ideal POD layout will specify every geographical and organizational detail necessary for an untrained crew to prepare a facility for use as a POD, and will be reviewed regularly to ensure compliance with changes in actual facility layouts.

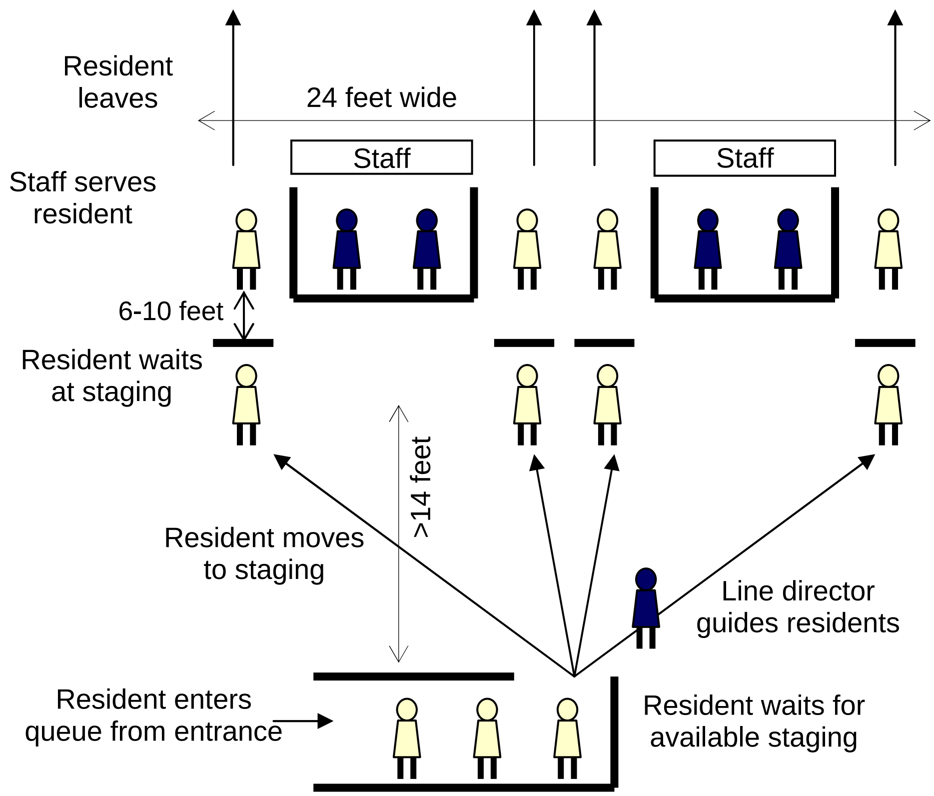
POD layout				
Does the overall layout include…	Complete	Incomplete	Missing	N/A
…separate entrances and exits to the POD and to each room that residents will visit? *Traffic moves more slowly when people traveling in opposite directions through the same door; using separate entrances and exits avoids this issue and keeps all the traffic inside the POD going in one direction.*	☐	☐	☐	☐
…a triage station outside the POD? *Residents with symptoms or contact with an agent should be separated from healthy residents as early as possible.*	☐	☐	☐	☐
…a separate evaluation rooms for symptomatic residents? *Once residents with symptoms are identified, they should be examined and either treated or returned to the main flow.*	☐	☐	☐	☐
…a separate evaluation rooms for residents who have reported contact with an agent? *Once contact residents are identified, they should be examined and either treated or allowed to return to the main flow.*	☐	☐	☐	☐
…provisions for sheltering residents from the elements while they wait outdoors? *Special arrangements may be necessary to ensure the comfort of special needs residents.*	☐	☐	☐	☐
…a quiet location for watching educational videos? *In PODs where educational videos are provided, they should be shown in a separate room, and be run continuously whenever there are residents waiting to see them. Where possible, use several smaller rooms rather than one large room to avoid large groups of residents arriving at the next station all at once.*	☐	☐	☐	☐

POD layout (continued)				
Does the overall layout include…	Complete	Incomplete	Missing	N/A
…a designated first aid area (equipped with basic supplies)?	☐	☐	☐	☐
…designated locations for storage of spare supplies?	☐	☐	☐	☐

Staff comfort				
Does the layout include…	Complete	Incomplete	Missing	N/A
…separate staff and resident entrances?	☐	☐	☐	☐
…a designated break area for staff to take scheduled breaks? *The break area should be somewhere away from the main flow of the POD – preferably in a separate room.*	☐	☐	☐	☐

Resident comfort				
Does the planned layout include…	Complete	Incomplete	Missing	N/A
…designated staff to assist residents who have further questions?	☐	☐	☐	☐
…flow control personnel to direct resident traffic?	☐	☐	☐	☐
…separate stations to accommodate residents with special needs? *Some residents may require assistance, such as an aide or interpreters.*	☐	☐	☐	☐
…comfortable accommodation for residents filling out forms? *When residents must complete forms, they should have a comfortable place to complete them - either clipboards or a seating area with tables; if clipboards are used, sufficient quantities must be available for all residents in the POD.*	☐	☐	☐	☐

Station layout (see illustration below for an example)				
Do individual station layouts include…	Complete	Incomplete	Missing	N/A
...sufficient space for residents who are waiting to be served? *To get an estimate of how many residents will be waiting on average, create a model with the Clinic Planning Model Generator software. Doubling this number will provide surge capacity for "rushes". Approximately 3' of floor space should be allowed for each person.*	☐	☐	☐	☐
…high visibility of available staff from the head of all lines? *Leaving some space between a waiting line and the service area makes it easier for residents to spot when a staff member becomes available. For lines that start in the center of the service area, as below, the line should be set back by at least 0.6 times the length of the service area. If the line starts at the end of the service area, it should be set back by at least 0.2 times the service area length.*	☐	☐	☐	☐
…resident staging at each station? *Staging means that the first resident in the queue waits near a staff member – for instance, behind a piece of tape on the floor - so that when that server finishes serving the previous resident, time isn't wasted while a resident walks from the main queue.*	☐	☐	☐	☐
…flow-through layouts for all stations? *In flow-through layouts, residents are served and then keep moving in the same direction, like a toll booth or a ticket booth at an amusement park. This prevents residents leaving the station from crossing paths with residents arriving, and improves the visibility of idle servers from the head of the queue.*	☐	☐	☐	☐


Resident leaves
24 feet wide
Staff
Staff
Staff serves resident
6-10 feet
Resident waits at staging
>14 feet
Resident moves to staging
Line director guides residents
Resident enters queue from entrance
Resident waits for available staging

Appendix C: Sample POD plan evaluations

Layout title: Montgomery County Smallpox Plan

Evaluator name: Mark Treadwell

Assessment date: 04 / 03 / 06

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POD Plan Assessment Worksheet

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- Complete. The item is included, along with all relevant details.
- Incomplete. The item is included, but some details are not given.
- Missing. The item is not included in the layout.
- Not applicable (N/A). The operational plan for the DVC makes this item unnecessary.

The ideal POD plan will specify the preparatory steps that should be completed and refreshed regularly before an event occurs as well as the procedures and personnel that are necessary to respond to a biological event.

Plan basics				
Does the plan include…	Complete	Incomplete	Missing	N/A
…the scope of events covered by the plan? *The plan should define the response for a specific size and type of event.*	■	☐	☐	☐
…the number of people who must be treated?	■	☐	☐	☐
…the timeframe allowed for treatment?	■	☐	☐	☐
…a list of stations in the POD and their descriptions? *The stations in a POD should be applicable to all POD sites.*	■	☐	☐	☐
…a flowchart of resident movement through the POD? *This flowchart describes the order in which residents may pass through stations and all possible routings.*	■	☐	☐	☐
…designation of party responsible for maintaining or activating each component of the plan?	☐	☐	■	☐
…compliance with NIMS command structure?	☐	☐	■	☐
…agreements with neighboring municipalities? *The NCR matrix (available at www.montgomerycounty.gov/apc) lists several areas where agreements may be helpful.*	☐	☐	■	☐

Facilities and supplies				
Does the plan include…	Complete	Incomplete	Missing	N/A
…identification of a command center?	☐	☐	■	☐
…identification of a secure storage facility with backup power where vaccines can be stored? *A memorandum of understanding should be obtained for this site.*	☐	☐	■	☐
...a list of approved POD sites, including maps? *"Approved" means a site has been surveyed, it meets the CDC's site requirements, and whoever controls it has agreed to its use as a POD (generally in a memorandum of understanding).*	☐	■	☐	☐
…names and contact info for staff liaisons for POD sites? *This person will be notified when the site is needed for a POD.*	■	☐	☐	☐
…procedures for disposing of waste from POD sites?	■	☐	☐	☐
…physical layouts for each POD site? *The POD Layout Assessment Worksheet offers guidelines for creating efficient layout designs.*	☐	☐	■	☐
…the locations of all supplies required for POD sites?	■	☐	☐	☐
…a way of getting supplies and equipment to POD sites?	■	☐	☐	☐
…procedures for staff to be transported to the POD sites?	■	☐	☐	☐
…literature and forms which can be reproduced for distribution?	☐	☐	■	☐
…clear denotations of where each station and queue is located? *Stations should be clearly marked with signs; queueing space can be designated by stanchions, tape markings, or other similar means.*	■	☐	☐	☐
…simple, highly visible signs telling residents where they should be going next? *Signs should display a single word or phrase, in multiple languages where appropriate, along with an arrow; they should be located for maximum visibility (for example, taped above head height on a wall, or hanging from a ceiling).* *Crowd control stanchions or lines marked on the floor are also useful in directing resident traffic.*	■	☐	☐	☐

Resident notification and treatment				
Does the plan include…	Complete	Incomplete	Missing	N/A
…procedures for alerting the public of a threat and the proposed response?	□	□	■	□
…a scheme for designating treatment sites and times for residents? *CDC guidelines offer examples of grouping residents by zip code or social security number.*	□	□	■	□
…agreements with local media for coverage and production of public service announcements? *A memorandum of understanding should be obtained.*	□	□	■	□
…details for the activation and staffing of a telephone hotline? *This hotline will be the point of contact for citizens with questions about response and treatment plans.*	□	□	■	□
…a designated method of resident transport to POD sites? *This may include residents within a certain radius traveling on foot; if residents will drive to the PODs, sufficient parking must be made available.*	■	□	□	□
…provisions for treatment of disabled residents, either by accessible POD sites or mobile treatment options?	□	□	■	□

Personnel				
Does the plan include…	Complete	Incomplete	Missing	N/A
…exercises and other training for POD staff?	■	□	□	□
…provisions for treating first responders? *Medication should be pre-positioned with first responders, for immediate use when the order is given.*	■	□	□	□
…the number of personnel (with and without medical training) required to staff PODs? *This number can be estimated using a Clinic Planning Model.*	■	□	□	□
… role description sheets for all personnel?	■	□	□	□
…identification of security personnel for POD sites? *Security may be provided by police or normal site staff.*	■	□	□	□

Layout title: New Jersey Mass Prophylaxis Guide

Evaluator name: Mark Treadwell

Assessment date: 04 / 03 / 06

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- Incomplete. The item is included, but some details are not given.
- Missing. The item is not included in the layout.
- Not applicable (N/A). The operational plan for the DVC makes this item unnecessary.

The ideal POD plan will specify the preparatory steps that should be completed and refreshed regularly before an event occurs as well as the procedures and personnel that are necessary to respond to a biological event.

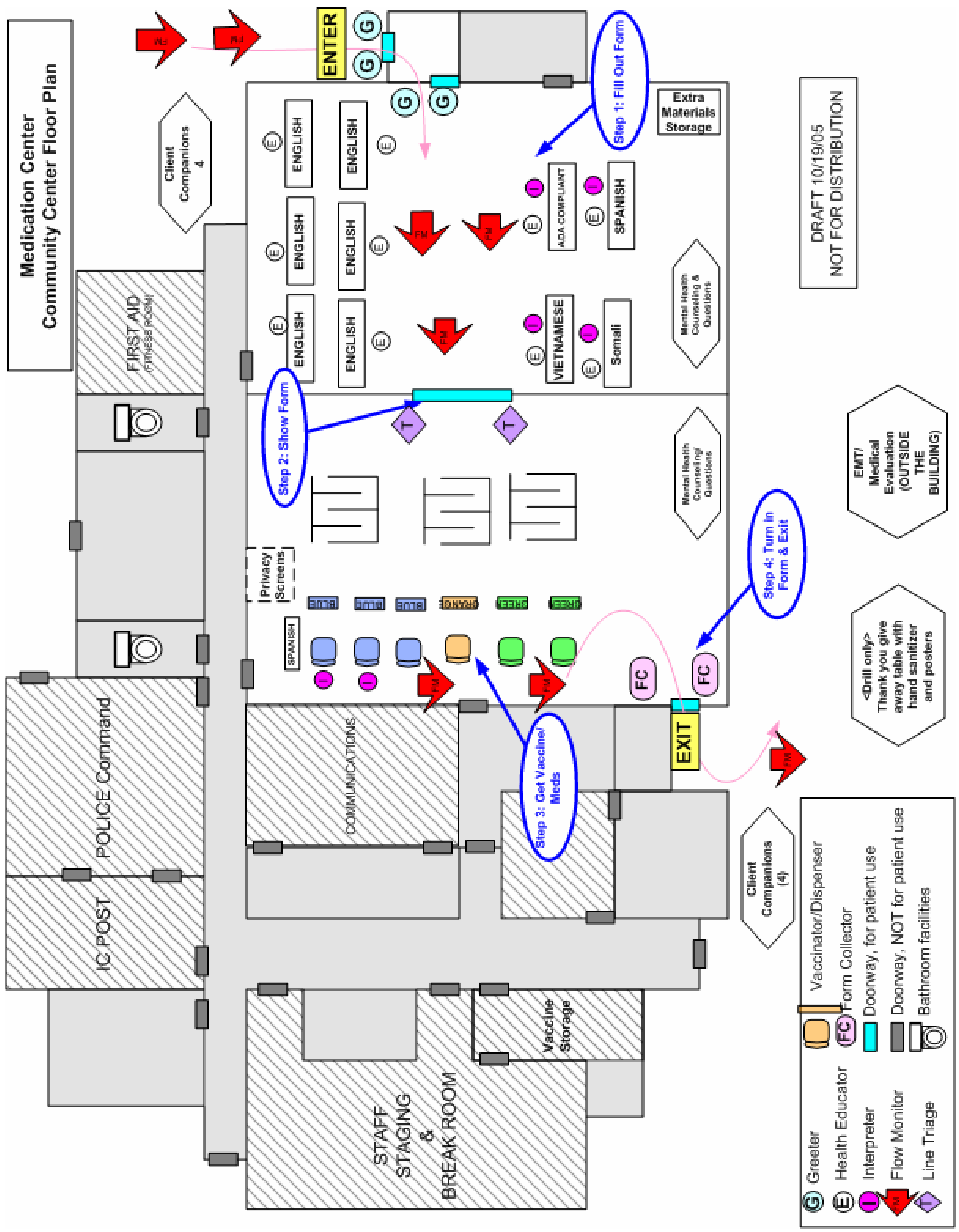
Plan basics				
Does the plan include…	Complete	Incomplete	Missing	N/A
…the scope of events covered by the plan? *The plan should define the response for a specific size and type of event.*	☐	☐	■	☐
…the number of people who must be treated?	☐	☐	☐	■
…the timeframe allowed for treatment?	☐	☐	☐	■
…a list of stations in the POD and their descriptions? *The stations in a POD should be applicable to all POD sites.*	■	☐	☐	☐
…a flowchart of resident movement through the POD? *This flowchart describes the order in which residents may pass through stations and all possible routings.*	■	☐	☐	☐
…designation of party responsible for maintaining or activating each component of the plan?	☐	☐	☐	■
…compliance with NIMS command structure?	☐	☐	■	☐
…agreements with neighboring municipalities? *The NCR matrix (available at www.montgomerycounty.gov/apc) lists several areas where agreements may be helpful.*	☐	■	☐	☐

Facilities and supplies				
Does the plan include…	Complete	Incomplete	Missing	N/A
…identification of a command center?	☐	☐	☐	■
…identification of a secure storage facility with backup power where vaccines can be stored? *A memorandum of understanding should be obtained for this site.*	☐	☐	☐	■
...a list of approved POD sites, including maps? *"Approved" means a site has been surveyed, it meets the CDC's site requirements, and whoever controls it has agreed to its use as a POD (generally in a memorandum of understanding).*	☐	☐	☐	■
…names and contact info for staff liaisons for POD sites? *This person will be notified when the site is needed for a POD.*	☐	☐	☐	■
…procedures for disposing of waste from POD sites?	☐	☐	☐	■
…physical layouts for each POD site? *The POD Layout Assessment Worksheet offers guidelines for creating efficient layout designs.*	☐	☐	☐	■
…the locations of all supplies required for POD sites?	☐	☐	☐	■
…a way of getting supplies and equipment to POD sites?	☐	☐	☐	■
…procedures for staff to be transported to the POD sites?	☐	☐	☐	■
…literature and forms which can be reproduced for distribution?	■	☐	☐	☐
…clear denotations of where each station and queue is located? *Stations should be clearly marked with signs; queueing space can be designated by stanchions, tape markings, or other similar means.*	☐	☐	■	☐
…simple, highly visible signs telling residents where they should be going next? *Signs should display a single word or phrase, in multiple languages where appropriate, along with an arrow; they should be located for maximum visibility (for example, taped above head height on a wall, or hanging from a ceiling).* *Crowd control stanchions or lines marked on the floor are also useful in directing resident traffic.*	☐	☐	■	☐

Resident notification and treatment				
Does the plan include…	Complete	Incomplete	Missing	N/A
…procedures for alerting the public of a threat and the proposed response?	■	□	□	□
…a scheme for designating treatment sites and times for residents? *CDC guidelines offer examples of grouping residents by zip code or social security number.*	□	□	■	□
…agreements with local media for coverage and production of public service announcements? *A memorandum of understanding should be obtained.*	□	□	□	■
…details for the activation and staffing of a telephone hotline? *This hotline will be the point of contact for citizens with questions about response and treatment plans.*	■	□	□	□
…a designated method of resident transport to POD sites? *This may include residents within a certain radius traveling on foot; if residents will drive to the PODs, sufficient parking must be made available.*	□	□	□	■
…provisions for treatment of disabled residents, either by accessible POD sites or mobile treatment options?	□	□	□	■

Personnel				
Does the plan include…	Complete	Incomplete	Missing	N/A
…exercises and other training for POD staff?	□	■	□	□
…provisions for treating first responders? *Medication should be pre-positioned with first responders, for immediate use when the order is given.*	■	□	□	□
…the number of personnel (with and without medical training) required to staff PODs? *This number can be estimated using a Clinic Planning Model.*	■	□	□	□
… role description sheets for all personnel?	■	□	□	□
…identification of security personnel for POD sites? *Security may be provided by police or normal site staff.*	■	□	□	□

Appendix D: Sample POD layouts and evaluations



Seattle-King County Community Center POD layout

Layout title: Seattle-King County Community Center

Evaluator name: Mark Treadwell

Assessment date: 03 / 31 / 06

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- Incomplete. The item is included, but some details are not given.
- Missing. The item is not included in the layout.
- Not applicable (N/A). The operational plan for the POD makes this item unnecessary.

The ideal POD layout will specify every geographical and organizational detail necessary for an untrained crew to prepare a facility for use as a POD, and will be reviewed regularly to ensure compliance with changes in actual facility layouts.

POD layout				
Does the overall layout include…	Complete	Incomplete	Missing	N/A
…separate entrances and exits to the POD and to each room that residents will visit? *Traffic moves more slowly when people traveling in opposite directions through the same door; using separate entrances and exits avoids this issue and keeps all the traffic inside the POD going in one direction.*	■	☐	☐	☐
…a triage station outside the POD? *Residents with symptoms or contact with an agent should be separated from healthy residents as early as possible.*	☐	■	☐	☐
…a separate evaluation rooms for symptomatic residents? *Once residents with symptoms are identified, they should be examined and either treated or returned to the main flow.*	☐	■	☐	☐
…a separate evaluation rooms for residents who have reported contact with an agent? *Once contact residents are identified, they should be examined and either treated or allowed to return to the main flow.*	☐	■	☐	☐
…provisions for sheltering residents from the elements while they wait outdoors? *Special arrangements may be necessary to ensure the comfort of special needs residents.*	☐	☐	■	☐
…a quiet location for watching educational videos? *In PODs where educational videos are provided, they should be shown in a separate room, and be run continuously whenever there are residents waiting to see them. Where possible, use several smaller rooms rather than one large room to avoid large groups of residents arriving at the next station all at once.*	☐	☐	☐	■

POD layout (continued)

Does the overall layout include…	Complete	Incomplete	Missing	N/A
…a designated first aid area (equipped with basic supplies)?	■	□	□	□
…designated locations for storage of spare supplies?	■	□	□	□

Staff comfort

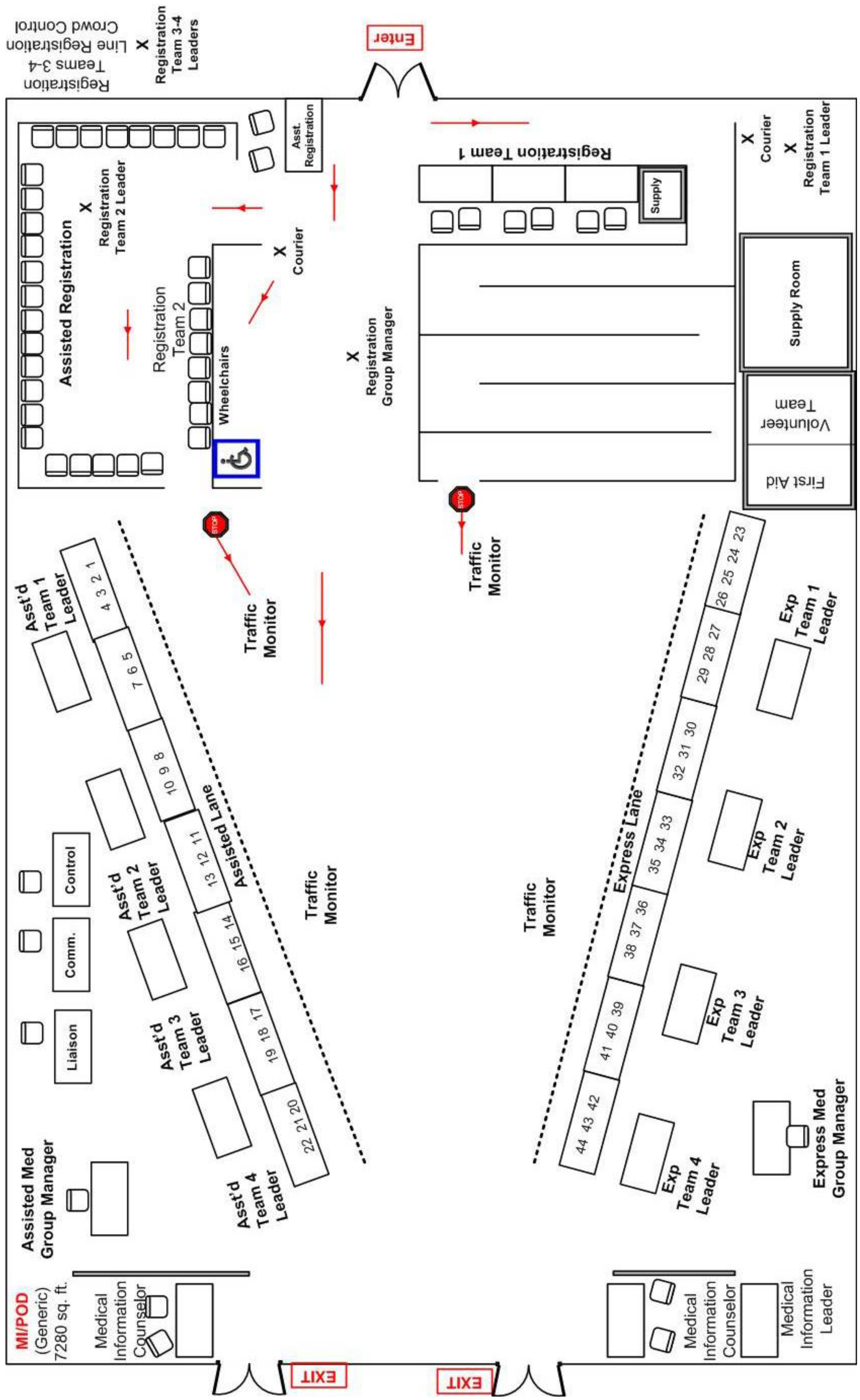
Does the layout include…	Complete	Incomplete	Missing	N/A
…separate staff and resident entrances?	□	■	□	□
…a designated break area for staff to take scheduled breaks? *The break area should be somewhere away from the main flow of the POD – preferably in a separate room.*	■	□	□	□

Resident comfort

Does the planned layout include…	Complete	Incomplete	Missing	N/A
…designated staff to assist residents who have further questions?	■	□	□	□
…flow control personnel to direct resident traffic?	■	□	□	□
…separate stations to accommodate residents with special needs? *Some residents may require assistance, such as an aide or interpreters.*	□	□	□	□
…comfortable accommodation for residents filling out forms? *When residents must complete forms, they should have a comfortable place to complete them - either clipboards or a seating area with tables; if clipboards are used, sufficient quantities must be available for all residents in the POD.*	□	■	□	□

Station layout (see illustration below for an example)

Do individual station layouts include…	Complete	Incomplete	Missing	N/A
...sufficient space for residents who are waiting to be served? *To get an estimate of how many residents will be waiting on average, create a model with the Clinic Planning Model Generator software. Doubling this number will provide surge capacity for "rushes". Approximately 3' of floor space should be allowed for each person.*	■	□	□	□
…high visibility of available staff from the head of all lines? *Leaving some space between a waiting line and the service area makes it easier for residents to spot when a staff member becomes available. For lines that start in the center of the service area, as below, the line should be set back by at least 0.6 times the length of the service area. If the line starts at the end of the service area, it should be set back by at least 0.2 times the service area length.*	■	□	□	□
…resident staging at each station? *Staging means that the first resident in the queue waits near a staff member – for instance, behind a piece of tape on the floor - so that when that server finishes serving the previous resident, time isn't wasted while a resident walks from the main queue.*	□	□	■	□
…flow-through layouts for all stations? *In flow-through layouts, residents are served and then keep moving in the same direction, like a toll booth or a ticket booth at an amusement park. This prevents residents leaving the station from crossing paths with residents arriving, and improves the visibility of idle servers from the head of the queue.*	■	□	□	□



Oklahoma City-County Health Department MI/POD Layout

Layout title: Oklahoma City County HD MI/POD

Evaluator name: Mark Treadwell

Assessment date: 03 / 31 / 06

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- Missing. The item is not included in the layout.
- Not applicable (N/A). The operational plan for the POD makes this item unnecessary.

The ideal POD layout will specify every geographical and organizational detail necessary for an untrained crew to prepare a facility for use as a POD, and will be reviewed regularly to ensure compliance with changes in actual facility layouts.

POD layout				
Does the overall layout include…	Complete	Incomplete	Missing	N/A
…separate entrances and exits to the POD and to each room that residents will visit? *Traffic moves more slowly when people traveling in opposite directions through the same door; using separate entrances and exits avoids this issue and keeps all the traffic inside the POD going in one direction.*	■	□	□	□
…a triage station outside the POD? *Residents with symptoms or contact with an agent should be separated from healthy residents as early as possible.*	□	□	□	■
…a separate evaluation rooms for symptomatic residents? *Once residents with symptoms are identified, they should be examined and either treated or returned to the main flow.*	□	□	□	■
…a separate evaluation rooms for residents who have reported contact with an agent? *Once contact residents are identified, they should be examined and either treated or allowed to return to the main flow.*	□	□	□	■
…provisions for sheltering residents from the elements while they wait outdoors? *Special arrangements may be necessary to ensure the comfort of special needs residents.*	□	□	□	■
…a quiet location for watching educational videos? *In PODs where educational videos are provided, they should be shown in a separate room, and be run continuously whenever there are residents waiting to see them. Where possible, use several smaller rooms rather than one large room to avoid large groups of residents arriving at the next station all at once.*	□	□	□	■

POD layout (continued)				
Does the overall layout include…	Complete	Incomplete	Missing	N/A
…a designated first aid area (equipped with basic supplies)?	■	□	□	□
…designated locations for storage of spare supplies?	■	□	□	□

Staff comfort				
Does the layout include…	Complete	Incomplete	Missing	N/A
…separate staff and resident entrances?	□	□	■	□
…a designated break area for staff to take scheduled breaks? *The break area should be somewhere away from the main flow of the POD – preferably in a separate room.*	□	□	■	□

Resident comfort				
Does the planned layout include…	Complete	Incomplete	Missing	N/A
…designated staff to assist residents who have further questions?	■	□	□	□
…flow control personnel to direct resident traffic?	■	□	□	□
…separate stations to accommodate residents with special needs? *Some residents may require assistance, such as an aide or interpreters.*	■	□	□	□
…comfortable accommodation for residents filling out forms? *When residents must complete forms, they should have a comfortable place to complete them - either clipboards or a seating area with tables; if clipboards are used, sufficient quantities must be available for all residents in the POD.*	■	□	□	□

Station layout (see illustration below for an example)				
Do individual station layouts include…	Complete	Incomplete	Missing	N/A
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…flow-through layouts for all stations? *In flow-through layouts, residents are served and then keep moving in the same direction, like a toll booth or a ticket booth at an amusement park. This prevents residents leaving the station from crossing paths with residents arriving, and improves the visibility of idle servers from the head of the queue.*	□	■	□	□

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