Improving Mass Vaccination Clinic Operations

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SYNOPSIS

To react to an outbreak of a contagious disease, county health departments have to set up and operate mass dispensing and vaccination clinics. Carefully planning these clinics before an event occurs is a difficult and important job. Two key considerations are the capacity of each clinic (the number of patients served per hour) and the time (in minutes) spent by patients in the clinic. This paper discusses a simulation model done to support this planning effort. Based on data from a time study of a vaccination clinic exercise, a simulation model was built and validated. This model was then used to evaluate alternatives to the clinic design and operation. The results show how batching and task assignments significantly impact clinic capacity and the average time that patients spend in the clinic.

1. INTRODUCTION

The threat of another large-scale terrorist attack on the United States has compelled public health departments to update and enhance their plans for responding to such an attack. This is especially true in densely populated regions and regions of significant importance such as the nation's capital. In the worst-case scenario, terrorists could release a lethal virus such as smallpox into the general population. If this were to happen, every person in the affected area would have to be vaccinated in a matter of days. For example, Montgomery County, Maryland, would need to vaccinate close to one million people. In order to vaccinate a large number of people in a short period of time, mass vaccination clinics would need to be set up at area high schools. Kaplan *et al.* [1] compare vaccination policies for responding to a smallpox attack, showing that mass vaccination results in many fewer deaths in the most likely attack scenarios.

Carefully planning mass vaccination clinics before an event occurs is a difficult and important job. Two key considerations are the capacity of each clinic (the number of patients served per hour) and the time (in minutes) spent by patients in the clinic (this is known as the time-in-system or cycle time or throughput time). Clinic capacity affects the number of clinics that must be opened and the total time needed to vaccinate the affected population. The time-in-system affects the number of patients who are inside the clinic. More patients require more space as they wait to receive treatment. If too many patients are in the clinic, they cause congestion, crowding, and confusion.

Clinic capacity and time-in-system are not the only concerns in planning such clinics. Based on mass prophylaxis operations in 2001, Blank *et al.* [2] describe many of the practical concerns that arise while planning and operating mass dispensing and vaccination clinics.

We are not aware of any other published reports that describe the modeling or design of mass dispensing and vaccination clinics. Malakooti [3] used a cell formation approach to emergency room design. Sanjay and McLean [4] describe a framework for linking simulation models of disasters.

The remainder of this paper is organized as follows: Section 2 discusses the creation and validation of the simulation model. Section 3 describes the simulation experiments. Section 4 presents the results. Section 5 concludes the paper.

2. MODEL CREATION AND VALIDATION

This study followed standard simulation study methodology:

1. Define scope of study.
2. Collect data.
3. Analyze data.
4. Build simulation model.
5. Validate simulation model.
6. Run experiments.
7. Present results.

The scope of the simulation study was limited to the clinic operations and the key performance measures of capacity and time-in-system. The clinic setup procedures, the transportation of patients to the clinic, and the handling of vaccines and other supplies were not considered.

Data collection relied upon a time study of a mass vaccination clinic exercise performed on June 21, 2004, by the Montgomery County Department of Health and Human Services (MCDHHS). This drill was created to simulate the emergency procedures in store for mass vaccination in the event of a widespread outbreak of the smallpox virus. The exercise was held at a local high school. No actual vaccinations were given. Nurses at the vaccination station simulated the smallpox vaccination step by poking each patient's arm with coffee stirrers.

In this full-scale exercise, 152 workers and volunteers served as medical professionals, clinic commanders, administrative staff, translators, and security. Volunteers from the local workforce and community served as patients. County workers and especially Public Health staff were encouraged to participate with their families. A number brought elderly family members and children, and the volunteers included individuals with physical disabilities. Approximately 530 people participated in the exercise as patients between 12:30 pm and 3:00 pm.

In the current clinic design, patients go through multiple stations to receive treatment. Figure 1 shows the patient flow.

Patients gather at the staging areas, from which school buses transport them to the clinic. Each bus holds up to 50 patients. At the clinic, each patient exits the bus and proceeds to the triage station, which is outside the clinic building. The triage staff ask patients if they have any symptoms of smallpox (a rash or fever) or if they know that they have been in contact with the smallpox virus. Symptomatic patients go to a holding room to await medical consultation. Patients exposed to the smallpox virus go to a quarantine room to await medical consultation. After seeing a doctor, each of these patients either goes to the hospital or enters the clinic. Each patient who enters the clinic receives registration forms (with English and Spanish instructions) and information on smallpox in multiple languages at the registration station. Patients then go to the education station.

The education station is a set of classrooms. In each

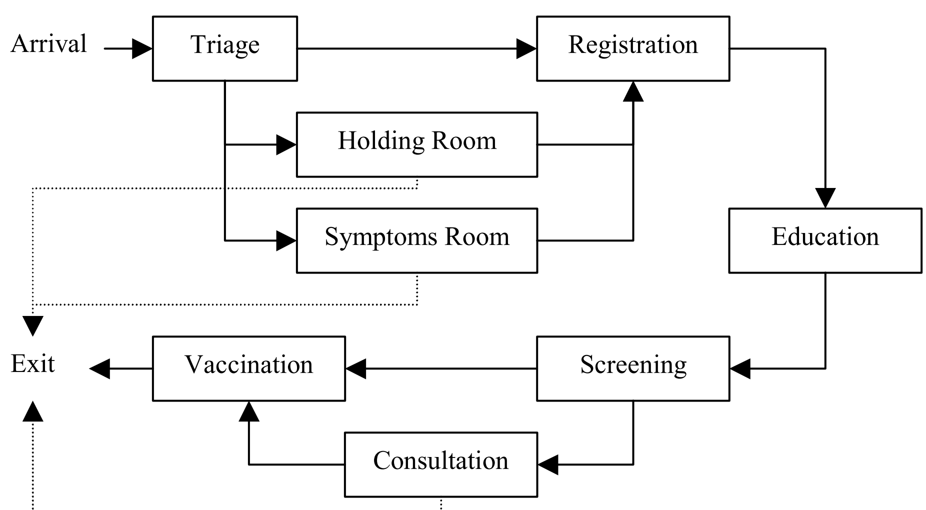

Figure 1. Flowchart of patient flow (dashed lines show patients who exit without receiving vaccinations)

classroom, 30 patients watch an informational video (in English or Spanish) about the smallpox vaccine. The patients also complete their forms. The staff overseeing these classrooms also check the registration forms for completeness. After this, each patient walks to the screening station.

At the screening station, screening staff checked each patient's registration form. Patients who have possible complications based on their medical history then go to the consultation station. The others sign a consent form and go directly to the vaccination station.

At the consultation station, each patient meets with a doctor to discuss possible complications. Patients who decide to skip the vaccination receive an information sheet and then leave the clinic. The others sign a consent form and go to the vaccination station.

At the vaccination station, vaccination staff verify that the consent form was signed and witnessed and then vaccinate the patient in one arm. The patient and a staff member review an information sheet about what to do after the vaccination, and then the patient leaves the clinic.

To model this clinic design, the research team constructed a discrete-event simulation model of the mass vaccination clinic using Rockwell Software's Arena®. As shown in Figure 2, the model included animation for visualizing the movement of patients through the clinic. For validation purposes, this initial model was created to simulate the clinic that operated during the exercise that occurred. For instance, patients arrived in batches that corresponded to the actual bus arrivals. In the simulation model, each patient's arrival to each station was noted and recorded. The processing times at each station were random variables whose distributions had the best fit to data collected from the time study. Patients were randomly sent to the holding rooms or to consultation using probabilities that corresponded to the actual frequencies.

Table 1 and Figure 3 compare the clinic performance from the exercise (measured as part of the time study) and the results from the simulation model. These results show that the measured and simulated times are close.

3. SIMULATION EXPERIMENTS

The purpose of the simulation experiments was to

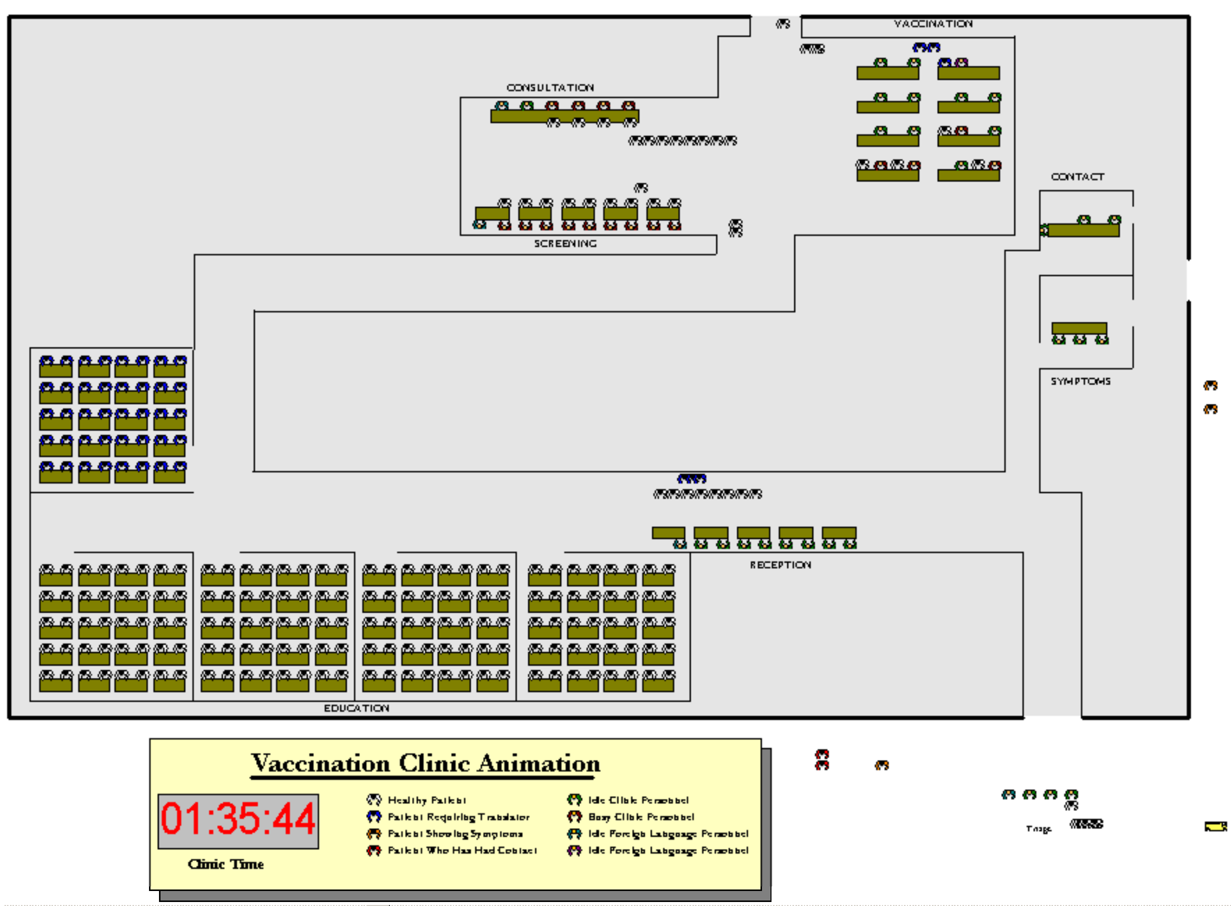

Figure 2. Clinic Simulation Model

Table 1. Model validation: average patient time-in-system

Station	Measured from exercise (minutes)	95% confidence interval from simulation (minutes)
Triage	2.18	4.35, 4.75
Registration	2.43	0.16, 0.17
Education	31.23	28.18, 29.65
Screening	16.77	20.08, 22.48
Vaccination	8.87	8.98, 9.98
Total in system	60.02	62.27, 65.03

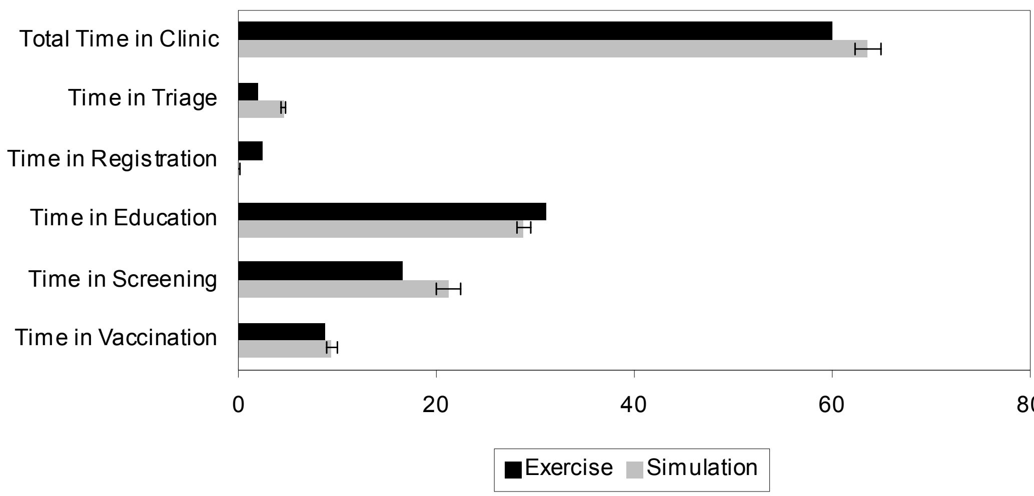

Figure 3. Model validation: average time-in-system

consider alternatives to improve clinic performance. These experiments considered the performance of the clinic under the steady-state conditions that would occur in a large event, when the clinic would be operating for several days. Therefore, in these models, buses arrive randomly with an exponential interarrival time. The mean interarrival time varies to consider different patient arrival rates.

In this paper, we consider two key design questions. First, would using an auditorium (instead of multiple classrooms) change clinic capacity or affect the average amount of time that patients spend in the clinic? Second, how would combining the screening and vaccination steps change clinic capacity or affect the average time that patients spend in the clinic? These questions were asked by public health professionals after viewing the initial simulation model.

For comparison purposes, a baseline clinic model was created. Table 2 specifies the number of staff at each station. (For education, this denotes the number of classrooms.) Each classroom holds 30 patients. Each arriving bus brings 50 patients. The key performance measure is the average total time in system. This was evaluated at five different arrival rates, shown in Table 3.

Table 2. Baseline clinic staffing.

Station	Number of Staff
Triage	5
Registration	8
Education	8
Screening	9
Consultation	6
Vaccination	16

Table 3. Patient Arrival Rates.

Arrival Rate (patients per minute)	Arrival Rate (patients per hour)	Percent of Clinic Capacity
2.45	147	50%
3.91	235	80%
4.40	264	90%
4.65	279	95%
4.84	291	99%

4. EXPERIMENTAL RESULTS

Significant changes to the simulation model were required to answer the questions posed above. To address the impact of using an auditorium for the education station, the classrooms were replaced with an auditorium that can hold 250 patients. In addition, it was necessary to consider different policies for operating the auditorium:

Policy 1: As soon as one group ("class") of patients is done, start the next class with those who are waiting. If there are less than 250 patients waiting, all of them enter and become the next class. Otherwise, the first 250 patients in line become the next class. (If there are no patients waiting, start the next class when any patient arrives.)

Policy 2: After one class is done, start the next class under the following conditions: If there are at least 250 patients waiting, the first 250 patients in line become the next class. Otherwise, let the patients waiting enter, but start when enough additional patients have arrived to fill the auditorium (with 250 patients) or when five minutes have passed since the last patient arrival.

Policy 3: Similar to Policy 2, but start when ten minutes have passed since the last patient arrival.

Policy 4: After one class is done, start the next class only when the auditorium is full (with 250 patients).

These policies and the baseline design were simulated with five different arrival rates. (Note that the auditorium has more capacity than 8 classrooms.) Figure 4 shows that all of the auditorium policies increase average time-in-system by over 40 minutes.

To address the impact of combining screening and vaccination, the vaccination station was removed. Patients who would, in the baseline design, go directly to vaccination from screening, receive their vaccination at the screening station. Patients who need to go to consultation go there without receiving a vaccination at the screening station. Patients who would, in the baseline design, go to vaccination from consultation, receive their vaccination at the consultation station. (Note that this design would require more people trained to give vaccinations, though the total number of staff remains the same.)

Initially, the 16 vaccination staff were added to the screening station (which then had 25 staff). The average processing time is 4.13 minutes. Thus, the station capacity was 6.05 patients per minute. Meanwhile, average processing time at the consultation station increased to 6.76 minutes, so that station's capacity was 0.89 patients per minute. This was clearly inadequate since 26% of the patients visited this station.

Moving four staff from screening (now with 21 staff) to consultation (now with 10 staff) reduced the screening station capacity to 5.08 patients per minute and increased the consultation station capacity to 1.48 patients per minute. This was adequate to meet demand.

This configuration and the baseline design were simulated with five different arrival rates. Figure 5 shows that the new configuration reduced average time-in-system by ten minutes in the scenarios with the highest arrival rate. Staff utilization remained the same.

5. SUMMARY AND CONCLUSIONS

This paper discussed the use of discrete-event simulation models to evaluate different mass vaccination clinic designs. These models allow county health departments to plan operations that reduce the number of patients in the clinic, which avoids unnecessary congestion, crowding, and confusion. In particular, the models show how batching at the education station degrades clinic performance. Plans that provide smallpox education before patients arrive to the clinic need to be investigated further.

Simulation provides the best estimates of queueing due to the batch processes and the general processing time distributions that characterize mass vaccination clinics. Simulation studies such as the one described here are most appropriate as part of planning a county's response to an event, since conducting the study requires time to collect and analyze data, build and validate the model, and conduct experiments to evaluate alternatives.

The authors are conducting research to build adaptable simulation models of common clinic designs. These parametric models will eliminate the need to construct a new simulation model from scratch. Additional research into collecting data about clinic operations is also ongoing.

Finally, simulation models that comprise multiple vaccination clinics, staging areas, and the transportation system used to move patients to and from clinics could be built using the clinic simulation models (or simplified versions of them).

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REFERENCES

1. Kaplan EH, Craft DL, and Wein LM. Emergency response to a smallpox attack: the case for mass vaccination. Proceedings of the National Academy of Sciences 2002; 99(16): 10935-10940.

2. Blank S, Moskin LC, and Zucker JR. An ounce of prevention is a ton of work: mass antibiotic prophylaxis for anthrax, New York City, 2001. Emerging Infectious Diseases 2003; 9(6): 615-622.

3. Malakooti NR. Emergency room design based on production, process planning, and cell formation. Proceedings of the 2004 Industrial Engineering Research Conference; 2004 May 15-19; Houston, Texas.

4. Sanjay J, McLean CR. An architecture for integrated modeling and simulation for emergency response. Proceedings of the 2004 Industrial Engineering Research Conference; 2004 May 15-19; Houston, Texas.

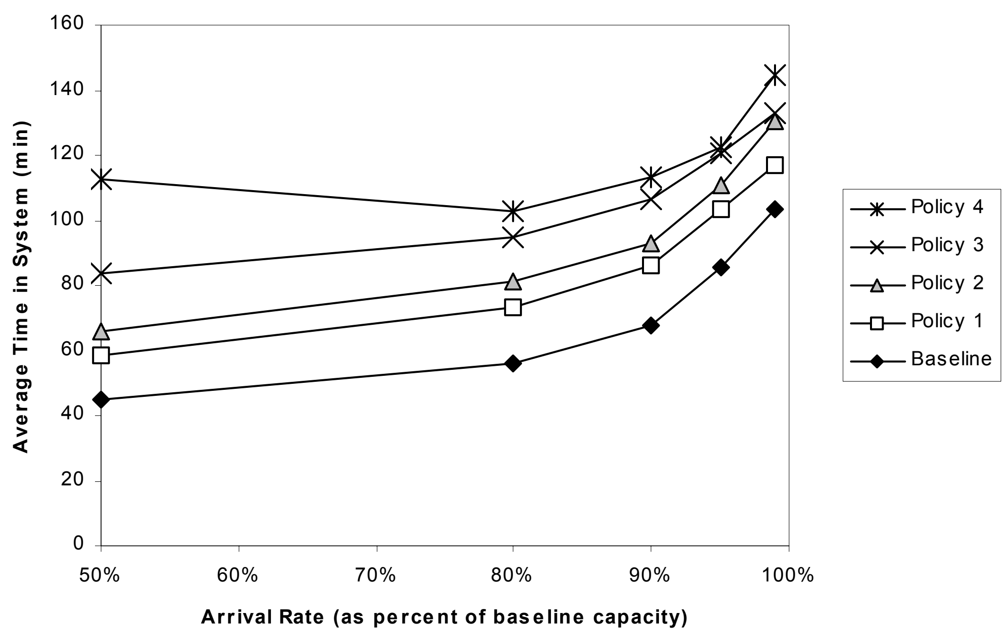

Figure 4. Clinic performance under the baseline policy and the four auditorium policies.

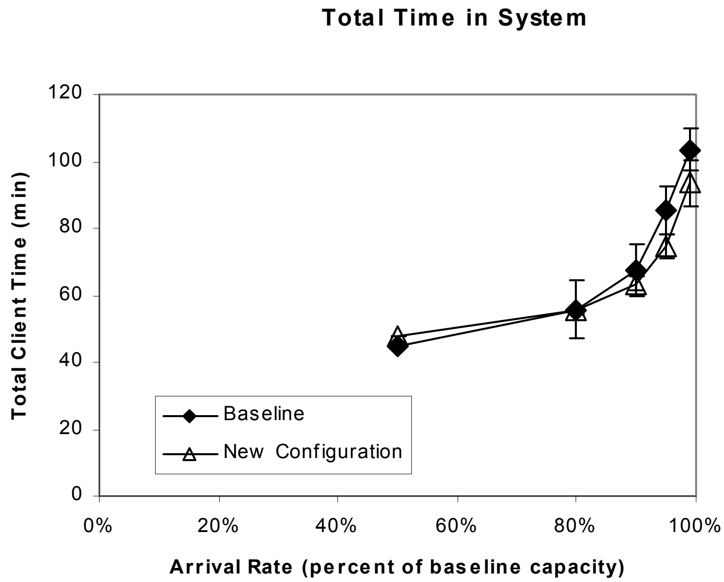

Figure 5. Clinic performance after combining screening and vaccination.