Proceedings of the 2008 Winter Simulation Conference
S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, J. W. Fowler eds.

ANALYZING DISPENSING PLAN FOR EMERGENCY MEDICAL SUPPLIES IN THE EVENT OF BIOTERRORISM

Young M. Lee

IBM T.J. Watson Research Center
1101 Kitchawan Road
Yorktown Heights, New York 10598, USA

ABSTRACT

To prepare for the event of bioterrorism, which could spread contagious disease such as anthrax, plague, smallpox, or tularemia to public, local governments in the United States are required have a plan for dispensing medical supplies such as vaccines and antibiotics to general public. The mass prophylaxis would need to cover millions of people in large cities in a short period of time. The distribution and dispensing plan of the medical supplies have to be effective since it would influence health and lives of many people, and there would be no time to fix or adjust plan once the emergency event occurs. In this work, we develop a simulation model to help a major U.S. city in evaluating the effectiveness of alternative dispensing plans and identifying improvement opportunities. This paper describes potential risks and generalized recommendations that can lead to developing effective supply chain and dispensing plans.

1 INTRODUCTION

There is a risk for bioterrorism in anywhere in the world including the United States. When the event were to happen, people in the affected area should be vaccinated or provided with antibiotics within a few days. The mass prophylaxis would need to cover millions of people in large cities in a short period of time. For example, in a wide-spread smallpox attack, the vaccination of all potential contact should take place within 4 days of exposure, and in the event of anthrax outbreak, distribution of antibiotics should take place within 2 days of the event. Therefore, a careful planning of dispensing and vaccination considering various risk factors and uncertainty is important because it would influence lives of many people and there is no time to fix or adjust plan once the emergency event occurs. When a bioterrorism occurs, the Center for Disease Control and Prevention (CDC) of the U.S. government ships the Strategic National Stockpile (SNS) of medical supplies to one or more of designated Receiving, Storing and Staging (RSS) warehouse for each cities or counties in 12 hours. Then, it is responsibility of each city or county to has a Point of Dispensing (POD) plan to transport the SNS supplies to each POD and dispense them to the general public.

Many cities and counties in U.S., including the LA County (Rickter and Khan 2007), Montgomery County (Aaby et al. 2006) and the city of San Antonio (Miller, Randolph, and Patterson 2006) have POD plans, which designate hundreds of buildings, such as schools, recreation centers, theaters, stadium and medical facilities etc, in the area where the dispensing and vaccination occur, and analyzed the POD dispensing plan. There are some guidelines issued by the U.S. Government. CDC (2007) published guidelines for planning for POD operation in 2001, and AHRQ (Agency for Healthcare Research and Quality) (2007) has published the Planning guide for mass prophylaxis and public health preparedness in 2004. However, there has not been any tool that can help cities and counties in developing and evaluating the effectiveness of their plans for supply chain operations and POD plans. Aaby et al. (2006), Lee at al. (2006) and Lee (2008), Whitworth (2006) used discrete-event simulation models and capacity-planning and queuing system model to analyze and improve clinic operations at POD location with focus on layout of clinic, resource, capacity, speed of dispensing and traffic; however, they didn't include distribution of medical supplies from CDC to RSS warehouses and to POD sites. Our model includes supply chain operations of vaccines and antibiotics from RSS to PODs as well as dispensing the medical supplies at POD sites.

Typically, many cities and counties of U.S. use simplistic and deterministic calculation, as shown in (1), for example (AHRQ 2007 and Rickter and Khan 2007). For example, if the population of a region is 4.8 million, and the target time for prophylaxis is 2 days (48 hours), and the patient flow is 1000 people/hours, then the number of POD required is calculated as 100, (4,800,000/(48x100)).

Similarly, if a city would like to have 50 PODs for the same number of population, the required throughput rate should be 2,000 people/hour, by (R=P/(T*N)).

$$N = \frac{P}{T \cdot R} \tag{1}$$

Where N = Number of PODS
P = Population
T = Target Time for Prophylaxis
R = Patient Flow Throughput Rate at POD.

However, this calculation (1), is a deterministic calculation, and is valid only with many assumptions, which include that the total population is exactly known, exactly same number of people would be serviced by each POD, and the throughput rate is constant, there is sufficient transportation capacity, and there is sufficient supply of medical supplies in each POD at all times. These assumptions are not valid at all in realistic environment. In reality, many stochastic factors and uncertainty exist in the distribution and dispensing processes. For instance, the total population (demand) are not known in exact number. The number of people who comes to each POD for vaccination are not same and not known in advance. The transportation time for medical supplies from RSS to POD has uncertainty; therefore, the availability of supplies at each POD is random and not constant. The time taken to activate each POD also varies, and therefore, the dispensing can start at different time at each POD. In this work, we develop a simulation model to help a major U.S. city in evaluating the effectiveness of alternative dispensing plan and identifying improvement opportunities, by considering many stochastic factors and uncertainty.

This study assesses and analyzes logistics and supply chain plans for distributing vaccines in the event of bioterrorism, through simulation modeling and analysis. The goal of this study is to determine ways to identify and resolve logistics and supply chain issues that could hinder SNS distribution and POD operations, thereby increasing the percentage of the population protected by prophylaxis within the specified CDC guidelines while enhancing the mass prophylaxis distribution readiness level of a city or county. In this paper, we describe analysis done only for dispensing vaccines in the event of smallpox attack. However, the finding from this study can also applied to prophylaxis of antibiotics or other medical supplies in the event of other bioterrorism such as anthrax attack.

Throughout the paper, we do not disclose any specific numbers for POD sites, location, supply quantity, policies and others because the study was done for a major city in U.S. and it is inappropriate to disclose information related the actual SNS/POD plan.

2 SIMULATION MODEL

Figure 1 shows the overview of the simulation model. The model consists of randomly sampling stochastic factors and flow of materials. The stochastic factors that are considered in the simulation model are:

- Total quantity of SNS medical supplies to be transported from the CDC to RSS warehouse
- Quantity of medical supplies shipped from the RSS warehouse to POD sites
- Transit (delivery) time and variability from RSS to PODs
- Capacity of trucks used for transportation
- Cross shipping of medical supplies from one POD site to another
- Number of people showing up at each POD site and variability
- Arrival patterns of victims at POD sites
- POD activation time
- Throughput of victim at POD sites

The medical supplies flow from SNS warehouse to PODs, between PODs, and from PODs to victims as shown in Figure 1.

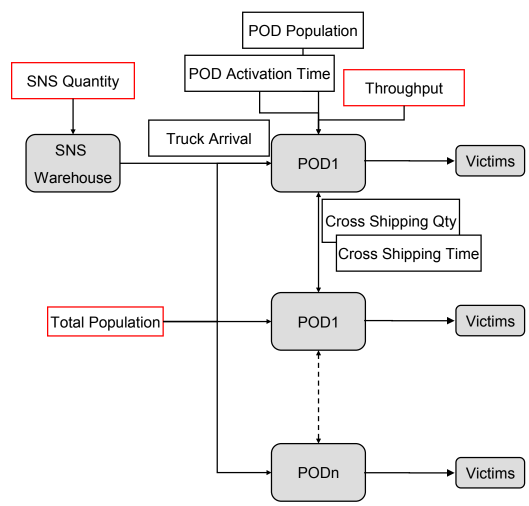

Figure 1: Overview of Simulation Model

The following performance metrics, which are indicators of the effectiveness of the SNS/POD logistics and supply chain plans, are analyzed and computed:

- Overall Coverage of Dispensing (percentage of the population who receives the vaccinations from the mass prophylaxis)
- Coverage of Dispensing at Targeted Time (percentage of the population who receives the prophylaxis within the targeted dispensing time, e.g., 4 days for smallpox vaccines)

3 SIMULATION RESULTS AND ANALYSIS

In this analysis, we first simulate a base case, which is a SNS/POD plan based on the idealistic assumptions and deterministic calculation, as shown in equation (1) above. Then, we assess the inefficiencies and identify opportunities for improvement. We then simulate the impact of each of those potential opportunities for improvement and compare the performance metrics with those of the base case. Finally, we summarizes the recommendation in the following section.

3.1 Simulation of Base Case

The base case is a scenario of SNS/POD plan which is based on simple deterministic calculations and assumptions, and it is often used in preliminary draft plan. The following are assumptions that are used in simulating the base case.

- The CDC provides a number of doses of smallpox vaccines that corresponds to exact number of population.
- There is a fixed number of POD sites, and the quantity of vaccines in RSS warehouse will be evenly distributed across all POD sites.
- The population for each POD site is normally distributed with a mean and a standard deviation.
- The vaccines are shipped to each POD once in the beginning of the POD site activations.
- Transportation time for vaccines from the RSS warehouse to the individual POD sites is uniformly distributed.
- The targeted completion time per the CDC national planning standard for smallpox prophylaxis is 4 days (96 hours).
- Patient throughput for dispensing at a POD site is normally distributed with a mean and a standard deviation.
- POD activation time (the time taken for a POD site to be ready to dispense from the POD activation decision) is uniformly distributed.
- People will not travel to another POD if their POD runs out of the supplies.

Figure 2 shows the dispensing profile for the base case simulation. At the end of the first day, the simulation results indicates that only 18.1% of the population is likely to be vaccinated, and the coverage would go up to 45.3% and 67.1% at the end of 2^{nd} and 3^{rd} day respectively, and finally 76.7% at the end of targeted dispensing time of 4 days (96 hours). The dispensing coverage (the number of people who were given the vaccination) is likely to increase only to a maximum of 78.2% at the end of 5^{th} day and would not increase anymore due to shortages at various sites. Therefore, over the duration of the mass prophylaxis the remaining 21.8% of the population is not likely to receive vaccinations because of a lack of vaccine at the POD sites where they report. This maldistribution is due to the fact that supplies to each POD location are equally distributed but the demands are different; therefore, some PODs will have shortage while other PODs will have surplus of vaccines. This situation is based on the assumption that when people show up at a site and the supply ran out, they do not go to another POD site which still has a supply. In reality, people are likely to travel to another POD when they realize that their POD of choice ran out of supplies. However, this is likely to happen after a delay (beyond the target dispensing time) and with some chaos. Since the focus of our analysis is mostly within the proximity of the targeted time, this assumption will not impact the analysis significantly.

The simulation results also show that about half of POD sites are likely to have an insufficient supply of vaccines to distribute to the people who request vaccination. The other half of POD sites will have various degrees of surplus. The profiles of shortage and surplus are shown in Figure 3, which shows number of PODs with a range of shortage or surplus. For example, with n representing 500 people, 8 PODs would have a shortage of between 0 and n (i.e. 500) doses, and 6 PODs would have a shortage of between n (i.e. 500) and 2n (i.e. 1,000) doses, and so on. For surplus side, 9 PODs would have a surplus of between and n (i.e. 500) doses, and 8 PODs have a surplus of between n (i.e. 500) and 2n (i.e. 1,000) doses. We use n instead of real number and show only a portion of shortage/surplus plot due to the sensitive nature of the actual numbers for the city that this study was done for.

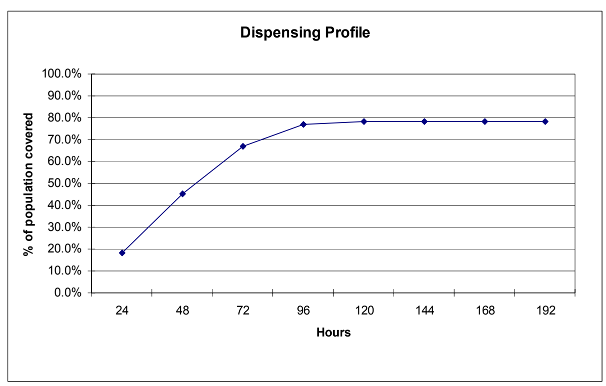

Figure 2: Dispensing Profile for Base Case

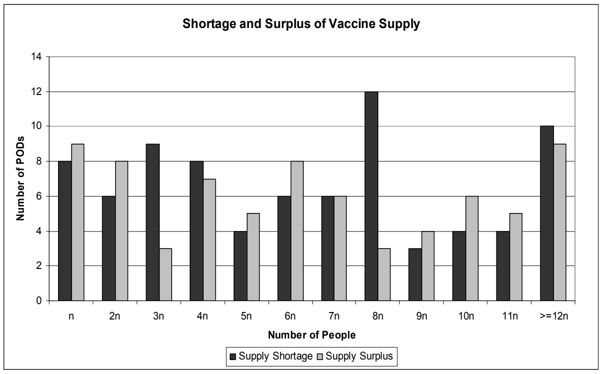

Figure 3: Shortage and Surplus of Supply for Base Case

In the dispensing profile (Figure 2), the time zero (t = 0) represents the time when the SNS/POD plans are activated, i.e., the time POD activation is initiated, and the RSS warehouse starts the process of shipping the vaccines to sites. It is assumed that the SNS supply is already at the RSS warehouse when t=0. The dispensing at a POD location starts only when the POD is activated and the initial shipment from the RSS warehouse arrives. Therefore, the dispensing start time is the longer of the POD activation time and SNS transportation time from the RSS warehouse to the POD sites.

The simulation results indicates that that there are two inefficiencies in the smallpox logistics and supply chain plans for the base case. One is the overall coverage of dispensing. Only about 78.2% of total population is likely to be covered by the base case plans due to a lack of stock of vaccine in over half of the POD sites. The base case plans call for smallpox vaccines to be evenly distributed across all POD sites, but the population is not evenly distributed across all the POD sites. In fact, it would be very difficult to choose POD sites in such a way that the populations which each POD supports are almost same. It would reasonable to assume that each POD site will have a different number of people showing up for prophylaxis. Therefore, it is critical that a more accurate distribution of the expected number of persons per POD site be obtained by estimating and calculating the population distribution. The other expected inefficiency is speed, i.e. a slow dispensing rate. At the end of the targeted 96 hours (4 days), the base case simulation shows that only 76.9% of all doses is likely be distributed.

There are two types of things need to be done in order to mitigate the inefficiencies. First, the dispensing needs to reach close to 100% to cover all the population (1). Secondly, the dispensing rate (speed) need to improve (2). Either one alone cannot move the coverage rate to 100% within the targeted time. Both have to be achieved together to reach 100% coverage within 4 days. In the following sections, several changes to the base case SNS/POD plans are simulated to see how they can reduce these inefficiencies and increase the potential for mass prophylaxis protection for the citizens.

3.2 Impact of Cross Shipping between POD sites

One of the inefficiencies of logistics and supply chain operations for the base case is low overall dispensing coverage due to sites running out of vaccine with no plan for re-supply. As shown in the simulation study in the previous section, there is a significant imbalance of demand versus supply at POD sites. The base case POD planning assumes smallpox vaccines are evenly distributed across all POD sites. However, each site must be expected to have a different and unknown number of people coming to receive the prophylaxis.

In this section, we explore the concept of cross shipping operations between POD sites to mitigate the imbalance between shortage and surplus. In this setting, surplus vaccines are shipped from POD sites experiencing a surplus to sites with projected shortages during the operation. We study this enhanced efficiency and enhanced vaccine coverage scenario through simulation. There are many variables that influence cross shipping operations, such as cross shipping time, minimum quantity for cross shipping and accuracy of estimating required cross shipping needs. For the sake of simplicity, we make the following assumptions. First, cross shipping time from one POD site to another is assumed to be uniformly distributed. It is also assumed that there is a minimum cross shipping quantity, and it can be incremented only by multiple of a fixed quantity. It is also assumed that determination of cross shipment quantity has accuracy, which is uniformly distributed. That is, the deviation between cross shipping quantity and actual shortage has an error, which is uniformly distributed. The rational for this assumption is that a POD would not know exactly how many extra doses it would need because it would not know exactly how many more people would still show up to receive vaccination. Therefore, the POD team and the RSS warehouse team would estimate the cross shipping quantity based on the customers served, populations expected for each POD site.

The dispensing profile for the cross shipping scenario is shown in Figure 4. At the end of the first day, only 18.1% of the population is likely to be vaccinated, and the coverage goes up to 45.3%, 67.2%, 80.9%, 88.8%, and 93.3% at the end of 2nd, 3rd, 4th, 5th and 6th days respectively. With cross shipping, the simulation result indicates that 96.7% of people who come to POD sites are likely to receive the vaccination compared to 78.2% for the base case SNS/POD Plan for the whole duration (which takes about 8 days) of prophylaxis. With cross shipping, only 3.3 % of the population would not receive the vaccination compared to 21.8% for the base case. At the targeted dispensing time (4 days), 80.9% of people will receive the vaccination compared to 76.9% for the base case. The shortages and surpluses in POD sites are much less than the base case plan as shown in Figure 5.

3.3 Impact of Variable Supply Quantity Among PODs

The base case SNS/POD plan assumes that the quantity of vaccines will be evenly distributed across all POD sites. Since the number of people who are going to show up at each POD site will be different, it would be more efficient to ship different quantities of vaccines to different POD sites based on the estimated population expected at each POD site. Therefore, this scenario is to use an alternate distribution concept based on order of magnitude quantity shipping. In this scenario, we simulate that different quantity of vaccines are shipped to each POD based on best estimate on the population it is expected to serve.

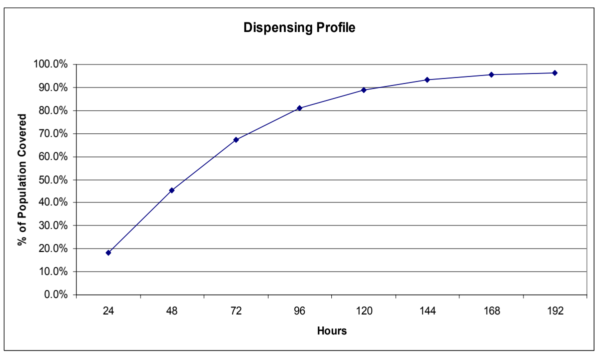

Figure 4: Dispensing Profile for Cross Shipping

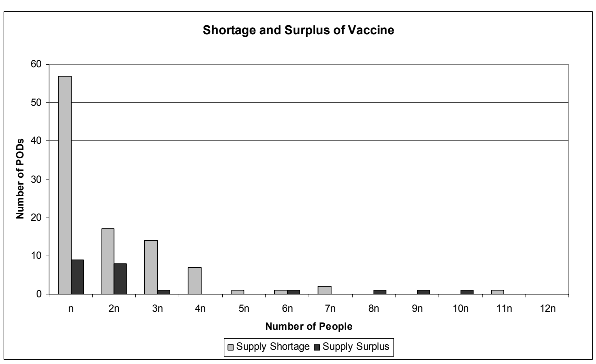

Figure 5: Shortage and Surplus for Cross Shipping

The following assumptions are made for this scenario. The number of vaccines shipped to each POD site is has a minimum quantity and it can be incremented only by a multiple of a fixed quantity. The rationale for this scheme is to artificially introduce error in estimating the population for each PODs, and to consider the smallest breakable (and shippable) shipment size.

The dispensing profile for the variable POD supply scenario is shown in Figure 6. At the end of the first day, only 18.0% of the population is likely to be vaccinated, and the coverage goes up to 44.7%, 65.5%, 79.6%, 87.4%, 91.5%, 93.5% and 94.0% at the end of 2nd, 3rd, 4th, 5th, 6th , 7th, and 8th days respectively. With the variable POD supply quantity, the simulation result in indicates that 94.3% of people who present for service at a POD site are likely to receive the vaccination compared to 78.2% for the base case, at the end of prophylaxis period, which takes about 8 days (192 hours). Only 5.7% of the population would not receive the vaccination compared to 21.8% for the current plan. This (overall coverage of dispensing) is a substantial improvement from the base case. However, at the targeted dispensing time (4 days), 79.6% of people receive the vaccination, which is essentially the same as the base case (76.9%). The variable shipping quantity method would substantially improve the first performance metric, the overall coverage of dispensing, but it would not improve the second performance metric, the coverage of dispensing at targeted time.

Figure 7 shows that the occurrences of shortages and surpluses in POD sites for the variable POD supply scenario are much less than the base case (as shown in Figure 2).

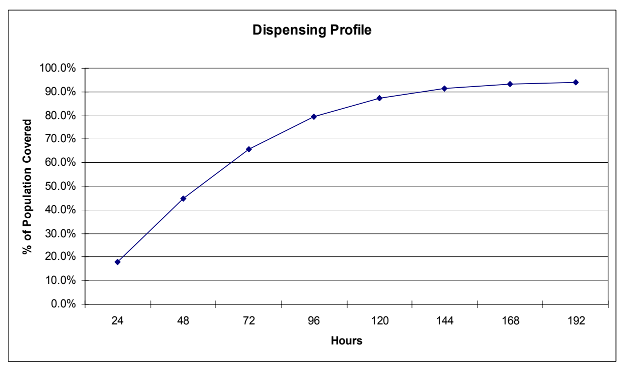

Figure 6: Dispensing Profile for Variable Supply Quantity

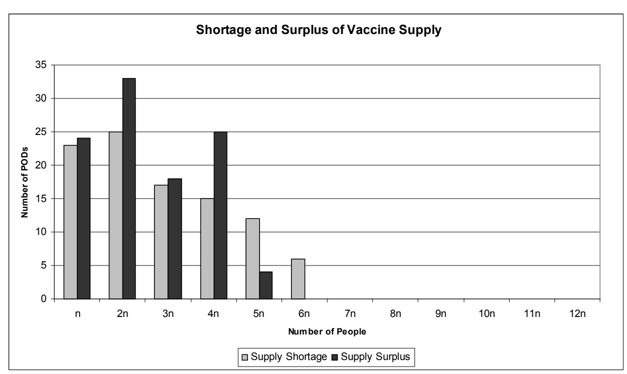

Figure 7: Shortage and Surplus for Variable Supply Quantity

3.4 Impact of High Throughout (with Cross Shipping)

As shown in the previous sections, both cross shipping and variable supply quantity shipping improves the first performance metric, overall coverage of dispensing, above that currently plotted in the plans. The coverage of dispensing requirements for the expected population improves from 78.2% to 96.7% with the cross shipping and improves to 94.3% with the variable supply quantity using the same capacity for transport vehicles. Adopting either of these methods will improve the distribution process, provide higher reliability for overall mass prophylaxis coverage, and will better utilize the SNS supply.

However, as noted, cross shipping and variable supply quantity do not improve the second performance metric, the coverage of dispensing within the targeted time (percentage of population who receive the prophylaxis within the targeted dispensing time). The coverage at the end of day 4 is simulated to be only 76.9% (current plan), 80.9% (cross shipping) and 79.6% (variable supply quantity). The percentage of the population who receive the prophylaxis within the targeted dispensing time can only be improved further by faster dispensing throughput at POD sites or more POD sites.

In this section, we simulate the scenario of cross shipping and at the same time increasing 40% of throughput (number of people per hour) with respect to the base case. We combined the higher throughput with cross shipping in this simulation because the higher throughput alone would not improve the coverage of dispensing within the targeted time if there aren't enough vaccines to dispense.

Figure 8 illustrates the dispensing profile, which shows that with the higher throughput the dispensing coverage is likely to be increased to 65.5% at 48 hours, while that of the base case is only 45.3%. The coverage goes up 86%, 95.5% at the end of the 3rd (72 hours) and 4th day (96 hours), respectively and to 96.7% at the end of the 5th day (120 hours), much faster coverage than previous scenarios. The simulation results using higher throughput of indicates that although the total dispensed is the same as the cross shipping scenarios (provided above) at 96.7%, the population covered within the target time frame (4 days) is 95.5%, much higher than the cross shipping case (80.9%) and the current plan (76.9%). As one might expect, the result confirms that the higher throughput, in fact, improves the speed of prophylaxis. Figure 9 shows that the occurrences of shortages and surpluses in POD sites for variable POD supply scenario are much less than the base case (as shown in Figure 2).

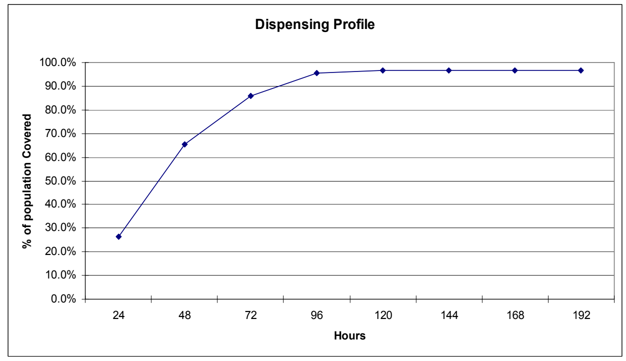

Figure 8: Dispensing Profile for Higher Throughput

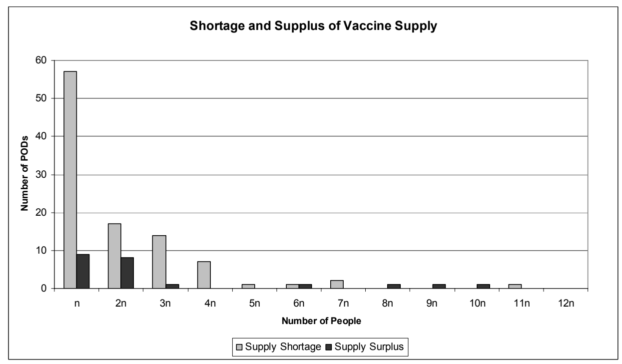

Figure 9: Shortage and Surplus for Higher Throughput

3.5 Impact of Safety Stock

If it were known exactly how many people are going to present for service at each POD site, SNS managers would know exactly how many doses of vaccines is needed at each site. However, there is uncertainty on how many people are going to present to receive the prophylaxis. In order to hedge against the variability of demand (number of people who are going to arrive for the prophylaxis), the quantity of medical supplies should have to be larger than the estimated demand (population). In this section, we analyze a scenario, which is the same as the base case plan but with a larger SNS supply quantity, including safety stock, provided to the RSS warehouse. In this scenario, the simulation assumes 50% more supply than projected population are requested and delivered to SNS warehouse from CDC. The transportation capacity is also assumed to be 50% more to proportionally provide for the number of trucks required for delivery. Optimal supply quantity can be calculated using a well-known Newsvendor model (Hopp & Spearman, 2001 etc.).

Figure 10 shows the dispensing profile. At t = 4 days, the coverage is 83.3% and it goes up to 94.6% at the end of 7^{th} day. With 50% more supply (over-supplying all the sites with safety stock), the total dispensed increases to 94.6% from 78.2% (base case), and the shortage goes down to 5.4% from 21.8%. The population covered within the targeted time of 4 days goes up to 83.3% from 76.9%; however, coverage is still well below the acceptable range as mandated by the CDC. As shown in the previous sections, only higher throughput will significantly increase the population coverage within the targeted time of 4 days. Figure 11 shows the profile of shortages and surpluses for this scenario. As expected, the shortage is much smaller than the base case plan, and the surplus is much higher.

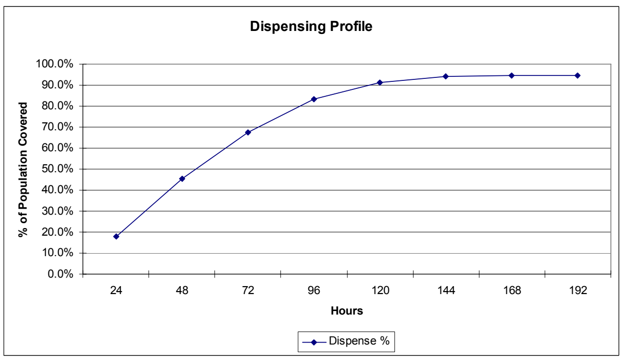

Figure 10: Dispensing Profile for Safety Stock

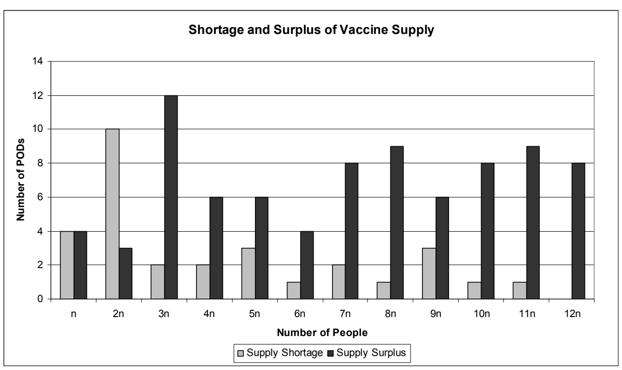

Figure 11: Shortage and Surplus for Safety Stock

3.6 Impact of Cross Shipping, Variable Supply Quantity, Higher Throughput and Safety Stock

In this scenario, the combined effect of all the changes (to the base case) in the previous four sections (3.2 - 3.5) are simulated and analyzed. The changes we simulate are: larger SNS supply (50% more); variable supply quantity for each PODs according to estimated population (with a certain error); cross shipping, and higher POD throughput (40% increase). The assumptions for this scenarios are the sum of assumptions of previous four scenarios.

The dispensing profile for this scenario is shown in Figure 12. The percentage of population who is vaccinated goes up quickly from 26.5% to 65.3%, 90.8%, 99.2% and finally to 100.0% at the end of 1st, 2nd, 3rd, 4th and 5th day. The simulation results indicate that with all four changes to the base case it would be possible to meet the CDC requirement of covering all the population within the targeted time, 4 days. The combined effect of the four changes would sufficiently mitigate the inefficiencies of the base case SNS/POD plan, speed, delay and coverage. In this scenario, the simulation result indicates that almost everyone (100%) of people who come to POD sites will receive the vaccination compared to 78.2% for the base case SNS/POD plan for the whole duration of prophylaxis. At the targeted dispensing time of 4 days, 99.2% of people will receive the vaccination compared to 76.9% for the base case. Compared to the error of simulation results, 99.2% essentially means almost everyone is covered.

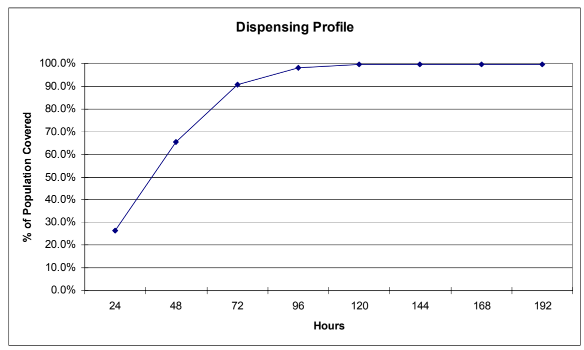

Figure 12: Dispensing Profile for Cross Shipping, Variable Supply Quantity, Higher Throughput and Safety Stock

4 FACTORS FOR GOOD DISPENSING PLAN

A simple, deterministic calculations for planning dispensing plan for medical supplies is not adequate for meeting CDC's requirement for mass prophylaxis of smallpox vaccines. Most of assumptions made for the deterministic calculation are not valid at all in realistic environment. In reality, there are many stochastic factors involved in the process. Based on the simulation result, the following actions are recommended to be included in the SNS/POD plan to satisfy the CDC requirements.

Cross shipping should be included into the dispensing plans. Cross shipping entails the shipment of surplus stocks from one POD site to another site in the same (or adjoining) section of a city or a county when a projected site shortage occurs following the initial distribution of medicine.

- A city should reserve a trucking capacity in each of the sections so that they can be used cross shipping. Cross shipping can be complemented by having a strategic reserve in RSS warehouse to fulfill reorders from shortages in PODs.
- Each POD should receive a supply quantity based on expected on expected demand in that POD instead of a fixed quantity for every PODs. A city should review the population data in and around each POD site, and then plan to ship the quantity (to the smallest breakable size) that is proportional to the estimated population for each POD site.
- Each POD should have sufficient throughput rates so as not to create a gating effect. To meet the dispensing time requirements for effective prophylaxis as determined by the CDC, a city should increase throughput if facilities and staffing can be appropriately adjusted. If the facilities are too small to handle a larger staff, consider activating more POD sites if additional staff is available.
- Requested SNS supply quantity should include a safety stock. Therefore, the supplies that a city receive should be higher than the target population planning figure. No one knows exactly how many people will present to receive prophylaxis in a city. Under-planning is a very high risk to take. In order to hedge against the variability of demand (the number of people who are going to arrive to receive the prophylaxis at sites), it is advised that the quantity of medical supplies shipped be larger than the estimated demand (population).

By implementing an appropriate combination of the above recommendations, a city or county would have better chance to reach close to 100% coverage of prophylaxis within the target time and meet CDC's requirements.

5 CONCLUDING REMARKS

Dispensing emergency medical supplies to all the potential victims in the event of bioterrorism in reasonable time is very important goal of emergency management agencies in federal and local governments. In this work, we study the logistics and supply chain plans that support Strategic National Stockpile (SNS) Plan and Point of Dispensing (POD) Plan for distributing smallpox vaccines, through simulation modeling and analysis. We identify potential weaknesses for a naïve plan, and make commendation for improvement.

There are two performance metrics we computed for this study. One is the overall coverage of dispensing (percentage of the population who receive vaccinations) from the mass prophylaxis. The other is the coverage of dispensing at targeted time (percentage of the population who receive the prophylaxis at the targeted dispensing time, e.g., 4 days for smallpox vaccination). The simulation results indicate the first performance metric, *overall coverage of dispensing*, can be improved by cross shipping, variable supply quantity delivery, and a larger supply quantity. The second metric, *coverage of dispensing at targeted time*, can be improved by higher throughput (as long as there is sufficient supply of vaccines).

In summary, we identify four factors that need to be considered for a good dispensing plan for vaccines and they are: cross shipping, variable supply quantity for each POD site; sufficient POD throughput; and safety stock of supply. Simulation is an effective tool to analyze what combination of the recommendations are needed to have effective dispensing plan. Dispensing plan for medical supplies in the event of bioterrorism has to be effective in the first time because there won't be time for fixing the plan without loss of many lives.

REFERENCES

AHRQ. 2004. Bioterrorism and Other Public Health Emergencies: Tools and Models for Planning and Preparedness: Community-Based Mass Prophylaxis, A Planning Guide for Public Health Preparedness, Agency for Healthcare Research and Quality. Available via <http://www.ahrq.gov/research/cbmprophyl/cbmpro.htm#down> [accessed March 25, 2008].

Aaby, K., J. Hermann, C. Jordan, M. Treadwell, K. Wood. 2006. Montgomery County's Public Health Service Uses Operations Research to Plan Emergency Mass Dispensing and Vaccination Clinics. *Interfaces* 36(6): 567-579.

Hopp, W., M. Spearman. 2001. *Factory Physics: Foundation of Manufacturing Management*. Irwin/McGraw-Hill, New York.

Miller, G., S. Randolph, J. E. Patterson. 2006. Responding to Bioterrorist Smallpox in San Antonio. *Interfaces* 36(6): 580-590.

Lee, E. K., S. Maheshwary, J. Mason, W. Glissom. 2006. Large-Scale Dispensing for Emergency Response to Bioterrorism and Infectious-Disease Outbreak. *Interfaces* 36(6): 591-607.

Lee, E. K. 2008. In Case of Emergency. *ORMS Today* 35(1): 28-34.

Rickter, A., S. Khan. 2007. Preliminary Analysis of Alternate Modes of Dispensing for LA County, unpublished work, presented at INFORMS International Conference 2007.

CDC. 2001. Smallpox Response Plan and Guidelines (Version 3.0). Centers for Disease Control and Prevention (CDC). Available via

<http://www.bt.cdc.gov/agent/smallpox/response-plan/index.asp> [accessed March 25, 2008].

Whitworth, M. H. Designing the Response to an Anthrax Attack. *Interfaces*, 36(6): 562-568.

AUTHOR BIOGRAPHIES

YOUNG M. LEE is a Research Staff Member in the mathematical science department of IBM's T.J. Watson Research Center. Dr. Lee received B.S., M.S., and Ph.D. degrees in chemical engineering from Columbia University. He joined the IBM Research Division in 2002, and has been working in the areas of supply chain simulation and optimization. Prior to joining IBM, he had worked for BASF for 14 years, where he had founded and managed the Mathematical Modeling Group, and led development of numerous optimization and simulation models for various logistics and manufacturing processes. His research interest includes simulation and optimization of supply chain, manufacturing, services and business processes. His email address is <ymlee@us.ibm.com>.