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# SIMULATING PUBLIC HEALTH EMERGENCY RESPONSE: A CASE STUDY OF THE 2004 NORTH CAROLINA STATE FAIR E.COLI OUTBREAK

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## ABSTRACT

Despite the investment of billions of dollars in federal funding towards emergency preparedness and response initiatives, broadly accepted performance measures for determining the efficacy of these systems have yet to be established. The inability to accurately capture this information creates knowledge gaps which hinder the ability to measure the true degree of preparedness. As a key communications component of North Carolina's public health system, the North Carolina Public Health Information Network (NC PHIN) serves as a promising means to measure emergency preparedness and response. We seek to determine how NC PHIN has increased emergency preparedness and response capacity by presenting a simulation of the 2004 State Fair E.coli Outbreak. We find that although the capacity exists within NC PHIN to increase emergency preparedness and response, other factors limit NC PHIN's effectiveness. Our findings suggest that proper resource allocation will be necessary in order to realize the true efficacy of NC PHIN.

## 1 INTRODUCTION

The attacks of September 11th, the 2005 Indian Ocean Tsunami and the recent Swine Flu Outbreak have all highlighted the need for more resilient and responsive public health infrastructures. Following the attacks of September 11th, a growing fear of a bioterrorist attack emerged within the United States and pushed the threat of bioterrorism to the forefront of the public health emergency preparedness and response agenda.(Association of Schools of Public Health 2004) As a result, an influx of funding to support the development of many public health emergency preparedness and response systems was provided to improve public health infrastructures. Given the sense of urgency that surrounded the development of many of these systems, very little oversight and detail was provided to determine how the efficacy of these systems would be governed, measured and evaluated. Despite the investment of more than six billion dollars towards public health emergency preparedness and response initiatives since 2001, many would agree that valid, well defined and broadly accepted performance measures have yet to be established. (Nelson et al. 2007; Levi et al. 2008)

In 2002, when federal funding became available to improve public health capacity, North Carolina made extensive improvements to their public health infrastructure. These improvements included the development of the Office of Public Health Preparedness and Response, the North Carolina Health Alert Network (NCHAN) and other vital emergency preparedness and response initiatives. As more funding became available, North Carolina continued to improve their public health infrastructure by implementing several capacity building information technology (IT) systems. These systems were developed as a part of North Carolina's Public Health Information Network (NC PHIN) to enhance the state's ability to monitor, manage, and respond to the health needs of its citizens.(North Carolina Public Health Task Force 2006) In addition to NCHAN, the other major electronic components of NC PHIN included the North Carolina Electronic Disease Surveillance System (NC EDSS) and the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT).

Because of the complex and dynamic conditions for which emergency preparedness and response systems must perform, it is becoming apparent that traditional measures of evaluating system performance simply won't suffice. While a lot of interdisciplinary research has been dedicated to modeling the more tangible aspects of emergency preparedness and response (e.g. spread of disease, number of hospital beds, transit capacity), major gaps still exist in our ability to quantify and validate the efficacy of the less tangible aspects such as the communication, information sharing and decision making processes.

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## 2 RESEARCH OBJECTIVES

The goal of this paper is to present a methodology for capturing the value of emergency preparedness and response systems, such as NC PHIN. Ultimately we seek to answer the following question: How has NC PHIN increased emergency preparedness and response capacity with respect to the ability to efficiently prepare for and respond to events that involve communicable diseases? In seeking to answer this question we develop a simulation model of the 2004 North Carolina State Fair E.coli Outbreak to quantitatively capture the capacity of the less tangible aspects of emergency preparedness and response systems.

## 3 LITERATURE REVIEW

Overall, an immense literature exists to address the many challenges within the emergency preparedness and response spectrum. Modeling techniques such as computer simulation and 3-D modeling have become an integral aspect of emergency preparedness and response studies as researchers seek to analyze past disasters and quantify the potential risks associated with new ones. (Radwan et al. 2005; Zhang et al. 2005; Johnston and Nee 2006) One of the most relevant models in the literature is provided Funk et. al (2009). The article presents a mathematical model to understand the impact that the awareness of a disease (which is defined as information obtained through either first-hand observation or word of mouth) has on the size of the outbreak and the epidemic threshold. (Funk et al. 2009) Their findings suggest that, in a well-mixed population, more informed hosts reduces susceptibility which can result in a lower size of the outbreak it does not affect the epidemic threshold. While the model quantifies the value of an intangible (i.e. awareness), however, it does not capture the value of awareness gained through IT that is captured in our model.

One of the most comprehensive studies of the use of modeling in emergency preparedness and response is provided by a position paper by Brandeau et al. in their review of exemplary and representative articles, published within the last 40 years, which address applied decision support modeling for emergency response.(Brandeau et al.) The study identified best practices in modeling and reporting of disaster response models and proposed recommendations for the design and reporting of such models. Although the study focused on emergency preparedness and response, there was no mention of models used to address the impact of IT on the capacity to respond or the impact of shared information on the capacity of the system or on health outcomes. The paper also notes the lack of attention to modeling the public health response to certain disasters by stating that “remarkably few published models have focused on public health and medical responses to such events”.(Brandeau et al.) The majority of the research in this area focuses on modeling outcomes that relate to disease prevalence, natural disaster relief, cost-effectiveness of various mitigation and intervention strategies and resource management.(Brandeau et al.)

Traditional public health capacity assessments rely on voluntary self assessments that measure performance and capacity according to meeting established benchmarks (typically driven by funding requirements) and checklists to count the existence of plans, resources and activities.(Federal Emergency Management Agency (FEMA) 1997; Scharf et al. 2002; Levi et al. 2008) Although existing preparedness instruments have provided some level of guidance for measuring emergency preparedness and response, the literature suggests that current measurement methodologies are insufficient, and provide a hollow perception of emergency preparedness and response capacity.(Davis et al. 2007; Jackson 2008)

As reflected in the literature, North Carolina has taken a vested interest in measuring the capacity and performance of emergency preparedness and response systems in their attempt to measure the return on investment of these initiatives.(Davis et al. 2004; Davis et al. 2007) One of the limitations of capacity assessments that have been conducted in North Carolina to measure preparedness is the frequent use of natural disaster preparedness as a measure of preparedness for all public health threats.(Davis et al. 2004) As a coastal state, this may be the result of more observable natural disaster opportunities and data. However, as experienced during the anthrax scare of 2001, “hurricane response doesn’t translate directly to bioterrorism response”.(Cline 2002) The existing literature suggests that the need for more resilient emergency response and preparedness systems is universally understood. Although considerable research has been dedicated to addressing emergency preparedness and response challenges, the impact of IT on response capacity, the focus of this paper has yet to be captured quantitatively or studied extensively.

## 4 METHODOLOGY

In order to obtain a thorough understanding of public health, communicable diseases and the public health infrastructure in North Carolina, multiple resources and approaches were used including: reviewing the existing literature, interviewing public health practitioners and analyzing data from NC PHIN’s IT components.

### 4.1 Selection of Case Study: The 2004 State Fair E.coli Outbreak

Due to the complexity of public health emergency response, prior to building our simulation model we narrowed the focus of our analysis down to a specific threat. The 2004 State Fair E.coli Outbreak was selected as a representative communicable disease outbreak in North Carolina.(Goode and O'Reilly 2005) The 2004 State Fair E.coli Outbreak case was selected for the following reasons:

- This event was one of the largest petting zoo outbreaks of E.coli to date.
- It was a statewide public health threat. Statewide events require communication across jurisdictions and organizations, which was an area we were interested in analyzing.
- The state fair attracted visitors from a variety of counties, providing the opportunity to observe the variability in response among the different counties.

### 4.2 Simulation Model Structure

The simulation model was designed to imitate the response process during an outbreak and to provide information about the impact that varying levels of access to information and resources had on public health response. In our model, the primary decision makers are individuals from the local health department (LHD) and from the North Carolina Department of Public Health who are represented as the State Health Department (SHD). We are modeling their ability to detect a public health threat based on the flow of information, which initiates the release of a threat alert. A major component of our simulation is the "awareness" of the decision makers and the alert recipients. In our model, awareness is represented as a percentage based on the number of cases people are aware of (i.e. the number of cases people have been informed of) relative to the true number of cases that actually exist in the system (i.e. the number of individuals who have been contaminated, both identified and unidentified cases). The level of awareness for the LHD's and SHD is represented by the number of cases in their respective queues (to be discussed in more detail later) and information provided by their level of access to NC PHIN components. Our simulation also reflects the awareness of the alert recipients who represent the vulnerable population. Once the threat detection trigger signals the release of the threat alert, information that was originally only known locally is released to the masses. Alert recipients are then able to make decisions based on the mass awareness of the information provided by the alert. However, the number of cases that alert recipients are aware of at the time of the alert is dependent on whether the LHD or SHD triggers the alert and their level of awareness (which is controlled by access to NC PHIN components). The alerts trigger the actions necessary to identify other cases in the system, identify the source of exposure and reconcile the threat.

Data from the 2004 State Fair E.coli Outbreak was used to develop the simulation model and for the quantitative analysis. Parameter values for the simulation were based on our review of the State Fair case data, our statistical analysis of NCHAN data, E.coli timeline data from the CDC (Centers for Disease Control and Prevention (CDC) 2006) and from interviews with public health practitioners. The objective of the simulation model was to imitate public health emergency response. This required developing a model that represented the role of the key organizations, resources and IT support systems of NC PHIN during the entire process that takes place when responding to a communicable disease related health threat. This process was divided into the following major steps:

1. Susceptibility (Exposure)
2. Reporting
3. Surveillance
4. Detection
5. Confirmation
6. Notification and Mass Dissemination of Information
7. Implementation of Control Measures

These major steps were reflected in the simulation model which was implemented using Arena 10.0. Figure 1 provides a screenshot of the Arena simulation model. The seven major steps are reflected in Figure 1 as indicated by the items in red font. The IT components of NC PHIN are indicated by the blue font and the resources are indicated by the green font. Appendix A provides a more detailed description of some of the input parameters used in the simulation model.

### 4.3 Simulation Logic

The seven major steps of the disease outbreak process, the key players and critical resources involved in the monitoring and control of a disease outbreak were represented in our simulation. The timing was controlled by the number of resources and access to the NC PHIN components defined within the model. Our simulation model focused on the flow of information with respect to the following key activities: the contamination of Petting Zoo Visitors with E.coli, the on-going process of identifying these cases, the detection of a threat, the release of an alert and alert recipient awareness. Petting Zoo visitors are the initial entities moving through the system, who progress through the seven major steps of the disease outbreak process as outlined in Figure 1. Each Petting Zoo Visitor that becomes contaminated with E.coli is defined as a case. Cases are further categorized as either probable, suspect or confirmed cases. As the cases progress through the simulation model, they seize and utilize the necessary resources (i.e. physician, lab and LHD personnel). As time progresses, the cases eventually enter a LHD or SHD queue. Cases waiting in a LHD or SHD queue represent a LHD's or SHD's local awareness of a case. Cases remain in their respective queues until a signal is sent for them to be released. The release of the cases from the queue implies mass awareness of the cases once they reach the "Threat Notification and Dissemination of Information" stage of the simulation. The timing of the threat alert is determined by the threat detection trigger. The timing of the threat detection trigger is determined by pre-established thresholds. These thresholds are based on access to the different IT components in the NC PHIN system which provides decision makers with varying levels of information and awareness about the number of cases in the system. Decision makers can only make decisions based on information provided by the number of cases in their queue and the number of cases provided by the NC PHIN components that they can access.

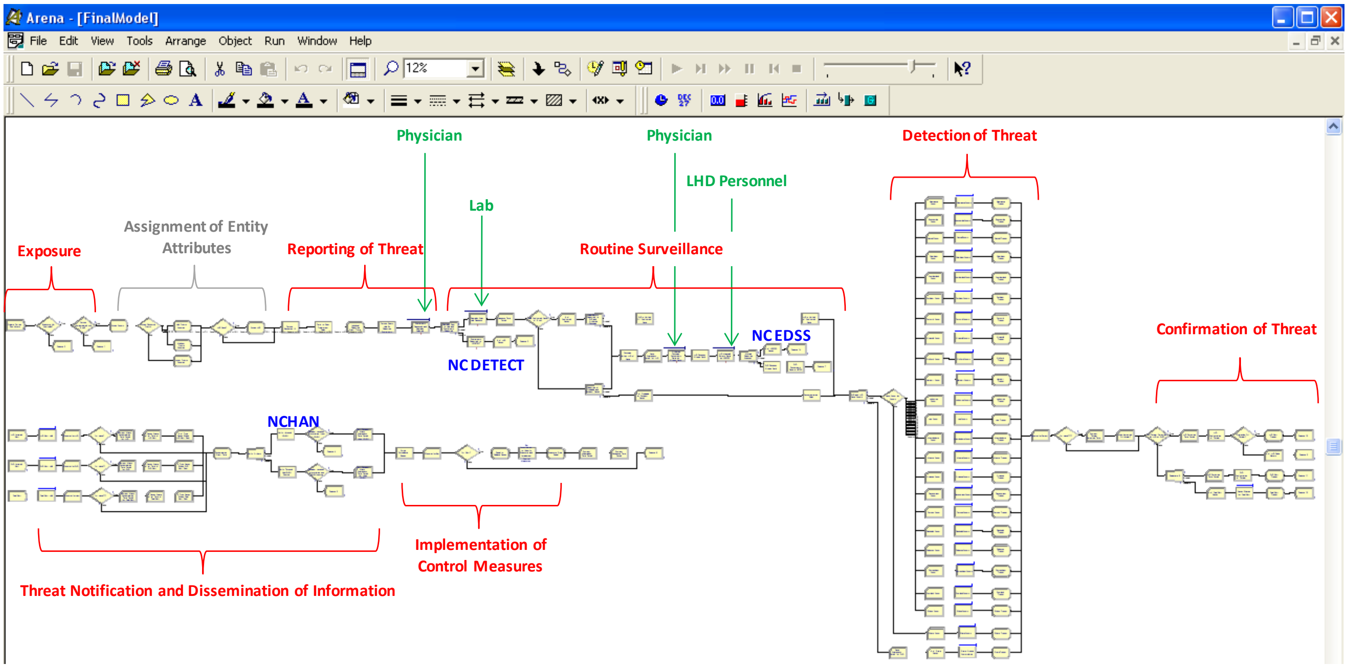

Figure 1: Screenshot of Simulation Model in Arena

### 4.4 Simulation Model Parameterization

The model was parameterized by first selecting the distributions of the random input variables based on the provided data sources and then varying the capacity levels of the resources until the simulation output data matched the real output data from the 2004 State Fair E.coli Outbreak as summarized below:

- Total of 108 cases
- Distribution of final case counts for each county matched real data distribution of final case counts for each county
- 15 cases diagnosed with Hemolytic Uremic Syndrome (HUS), a severe, life-threatening complication of E.coli
- Three NCHAN alerts sent on the following days with awareness of the following cases:
    - October 30, 2004 by Wake County (Aware of 3 HUS cases)
    - November 1, 2004 by NC DPH (Aware of 16 cases)
    - November 6, 2004 by NC DPH (Aware of 47 cases)

Output conditions were based on running one hundred replications which provided confidence intervals within 5% of the output averages. The verification of the simulation model was accomplished by testing extreme regions of the input parameters (stress testing).

## 4.5 Performance Metrics

An important part of our analysis involved defining the evaluation metrics. With the goal of ensuring that during a public health event people “get the right information, to the right people at the right time”, we established performance metrics to identify key determinants that would impact capacity, awareness and overall system performance. We ran multiple “what-if” scenarios of the 2004 State Fair E.coli Outbreak. The purpose of running the multiple scenarios was to evaluate the impact of changes in capacity on the performance of the system and its components. The following performance metrics were collected:

- NC PHIN System Performance Metrics
    - Total Number of Outbreak Cases
    - System Vulnerability Time Period: Time from first case exposure to implementation of control measures
    - System Threat Detection Time Period: Time from first case exposure to initial detection of statewide threat
    - System Response Time: Time from detection to implementation of control measures
    - Alert Recipient Awareness Level: Percentage of cases (either probable, suspect or confirmed – based on diagnosis) that the alert recipient is made aware of at time of alert

## 4.6 Mathematical Representation of Capacity

Since our simulation analysis is centered on capacity-based performance, a critical aspect of our methodology required a clear definition of capacity. The World Health Organization defines capacity for emergency management as "information, authority, institutions, partnerships" and the "plans, resources and procedures to activate them". We interpreted these definitions as follows: response capacity is a function of information, authority, institutions, partnerships, plans, resources, and the procedures to activate them. Mathematically we represented response capacity as a level of output that is dependent upon various inputs (or preparedness capacity elements) as represented by the following function:

*Response Capacity = f(preparedness capacity),*
*where preparedness capacity = [information, authority, institutions, partnerships, plans, resources, procedures]*

In our simulation, the NC PHIN performance metrics served as indicators for our measurement of response capacity. The representation of the various preparedness capacity elements (inputs) are reflected in our simulation model as detailed below:

- Information is represented by access to information provided from the IT components of NC PHIN (NCHAN, NC EDSS, NC DETECT), phone calls, emails, and other means of communication (fax, pager, listserv)
- Authority is represented by the ability of a LHD or SHD to trigger and issue an alert
- Institutions are represented by the organizations acting as decision makers and information providers in the simulation (i.e. LHD, SHD, hospitals, labs)
- Partnerships are represented by the communication between the various organizations and institutions in the model which is reflected by the reporting of diseases, alerting of the masses and confirming of threats among the different organizations and institutions
- Plans are reflected by the sequence (the seven major steps) and flow of information within the simulation that represents the general protocol for the monitoring and control of communicable disease related threats
- Resources are the labs, physicians and LHD personnel
- Procedures are reflected by the signals that must be activated (by triggers) before certain activities can take place such as the implementation of control measures

The key inputs in our assessment of NC PHIN’s ability to increase emergency preparedness and response capacity were information (specifically information as a result of IT) and resources (capacity of labs and the human resource (HR) levels in hospitals and LHD’s).

## 4.7 Design of Experiments

The goal of our simulation analysis was to determine how changes to certain preparedness capacity elements impacted response capacity (as indicated by our performance metrics). To accomplish this we designed five experiments, each with different levels of access to IT components in NCPHIN which represented changes to the information element of preparedness capacity (denoted as IT, i.e. technology based information). The varying levels of access to the NC PHIN components that are available to use as a resource in each experiment are listed below:

- Experiment 1: IT Access– NCHAN

- Experiment 2: IT Access– NCHAN & NC DETECT
- Experiment 3: IT Access– NCHAN & NC EDSS
- Experiment 4: IT Access –NC DETECT & NC EDSS
- Experiment 5: IT Access – NCHAN, NC EDSS & NC DETECT

We varied the level of access to the NC PHIN components by controlling which IT systems decision makers had access to during our simulation of the 2004 State Fair E.coli Outbreak. This was accomplished by changing the parameters of the hold condition in certain modules. For each experiment we ran seven scenarios. For each scenario, we varied the HR and lab capacities (which represented changes to the resource element of preparedness capacity) as listed below:

- Scenario 1: Base Case
- Scenario 2: Decrease HR Levels in Hospitals by 50%
- Scenario 3: Decrease HR Levels in LHDs by 50%
- Scenario 4: Decrease Lab Resources by 50%
- Scenario 5: Increase HR Levels in Hospitals by 50%
- Scenario 6: Increase HR Levels in LHDs by 50%
- Scenario 7: Increase Lab Resources by 50%

Changes to HR levels in hospitals and LHD's, was reflected by increasing or decreasing the number of physicians and LHD personnel available to process case information, respectively. Changes in lab resource levels reflected changes in the number of labs, lab personnel and other vital lab resources available to process case information. The percentage increases and decreases in HR levels and lab resources are relative to the base case. The capacity parameters, detection thresholds and other metrics for the base case were selected based on our analysis of the data from the 2004 State Fair E.coli Outbreak.

The scenarios for each experiment were managed using the Process Analyzer Tool in Arena 10.0. The data from the scenarios was used in our analysis of the impact of changes in preparedness capacity elements (i.e. IT access, HR levels and lab resources) on the NC PHIN system performance metrics.

### 4.8 Model Assumptions

The analysis was based on the following assumptions:

- Mass awareness (about the true number of cases in the system) among the alert recipients decreases susceptibility (exposure)
- Shorter time periods represent faster response times which reflect better system performance
- Control measures (which stop the exposure) are implemented as soon as the source and mode of transmission are known
- Local awareness of cases does not improve mass awareness among the alert recipients until this information is disseminated to the masses
- Long queue times in a process followed by significantly shorter queue times in subsequent stages of the process can be used as an indicator to identify bottlenecks in the system

## 5 RESULTS

In considering the purpose of an information network, such as NC PHIN, it is crucial that these systems have the ability to deliver "the right information, to the right people, at the right time". The focus of this analysis is the "Alert Recipient Awareness Level" metric, because it serves as an indicator for the accuracy (getting the right information to the right people) and timeliness (getting information at the right time) of information being delivered. The diagram depicted in Figure 2 provides our interpretation of the quality of the information which is a factor of the accuracy and timeliness of information. As reflected by Figure 2, when analyzing the alert recipient awareness level over time, we see that results falling in quadrants I and IV have higher quality information (i.e., higher accuracy in less time) and lower quality information (i.e., less accuracy and slower), respectively. Whereas quadrants II and III require a tradeoff in the quality of information because although quadrant II provides more accurate information than quadrant III, it is at the expense of receiving the information in a less timely manner. Within the context of NC PHIN performance metrics, awareness is measured with respect to the awareness level of the alert recipients, who represent the vulnerable population. Figures 3 through 6 illustrate the impact of changes in IT access, lab resources and HR levels on alert recipient awareness level over time. The percentage is based on the number of cases that the alert recipients are aware of relative to the true number of cases that are in the system at the time of the alerts. As indicated by Figures 3 and 4, where the level of access to IT components is being varied, we see the clustering of experiments 1 and 3 versus experiments 2, 4 and 5. Since IT access to NC DETECT is the distinguishing factor of these two clusters, our results indicate that, with respect to the NC PHIN components, NC DETECT has the most significant impact on alert recipient awareness level. The results also show that experiments 2, 4 and 5 provide higher quality information (more accurate and more timely) then experiments 1and 3. Although experiments 2, 4 and 5 provide higher quality information, experiments 1 and 3 suggest the improvement in alert recipient awareness levels over time is more significant as indicated by the steeper slopes of experiments 1 and 3 versus experiments 2, 4 and 5.

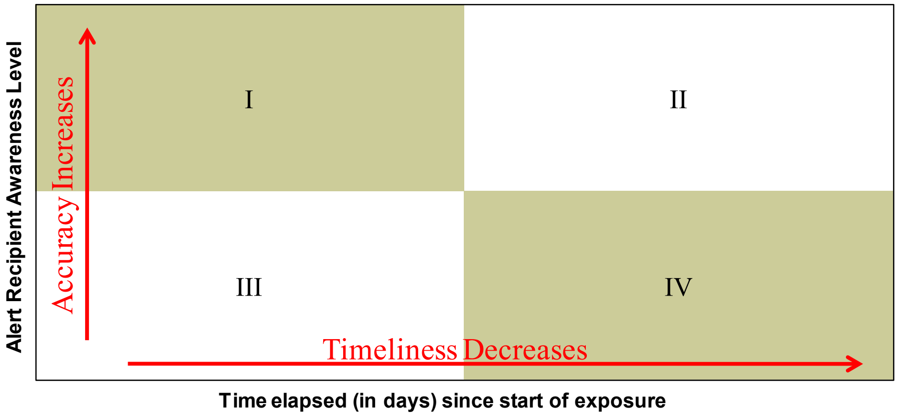

Figure 2: Interpretation of Timeliness and Accuracy of Alert Recipient Awareness Level Over Time

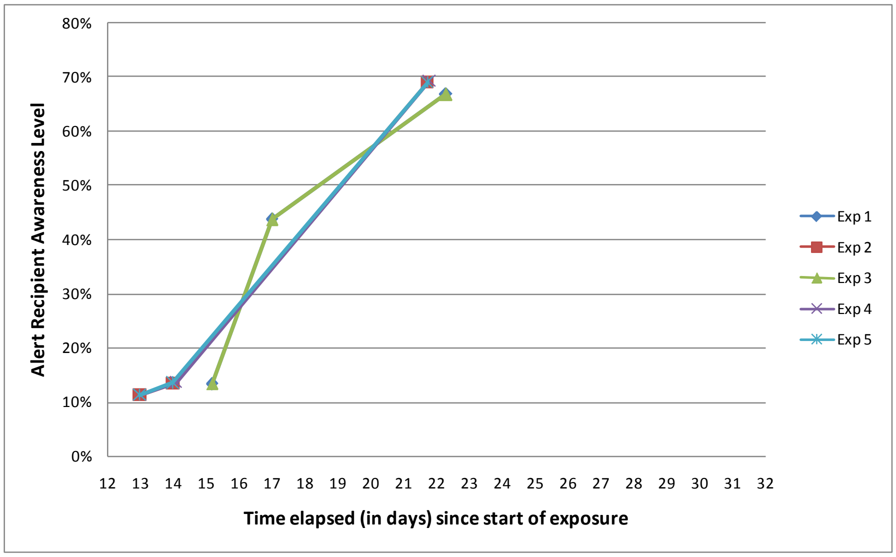

Figure 3: Alert Recipient Awareness Level Over Time for Scenario1. *E*xp 1: NCHAN; Exp 2: NCHAN & NC DETECT; Exp 3: NCHAN & NC EDSS; Exp 4: NC DETECT & NC EDSS; Exp 5: NCHAN, NCEDSS & NCDETECT

Figures 5 and 6, which show the impact of varying the HR levels and lab resources, indicate that changes to lab resources and the HR levels in hospitals have the most significant impact on alert recipient awareness level over time. The results also suggest that increasing and decreasing capacities by the same percentage does not have an equivalent impact on alert recipient awareness levels as indicated by the significant decrease in alert recipient awareness level when lab resources are decreased in comparison to the slight improvement seen when these resources are increased by the same percentage. Although many would assume that increases in capacity and alert recipient awareness levels are positively correlated, our findings indicate otherwise as indicated by the clustering of scenarios 1, 3, 5 and 6. We hypothesize that bottlenecks within the system may be responsible for the lack of improvement in alert recipient awareness levels seen in some scenarios despite increases in capacity for certain resources.

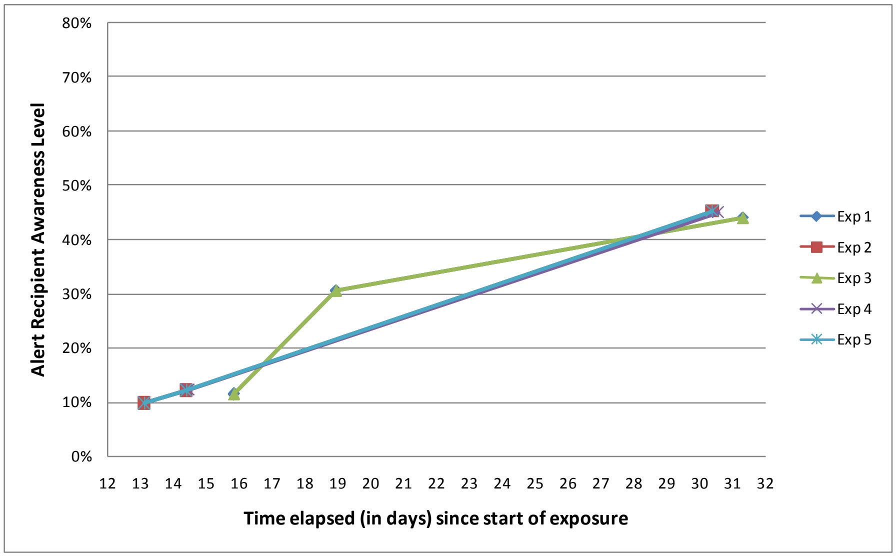

Figure 4: Alert Recipient Awareness Level Over Time for Scenario 4. Exp 1: NCHAN; Exp 2: NCHAN & NC DETECT; Exp 3: NCHAN & NC EDSS; Exp 4: NC DETECT & NC EDSS; Exp 5: NCHAN, NCEDSS & NCDETECT

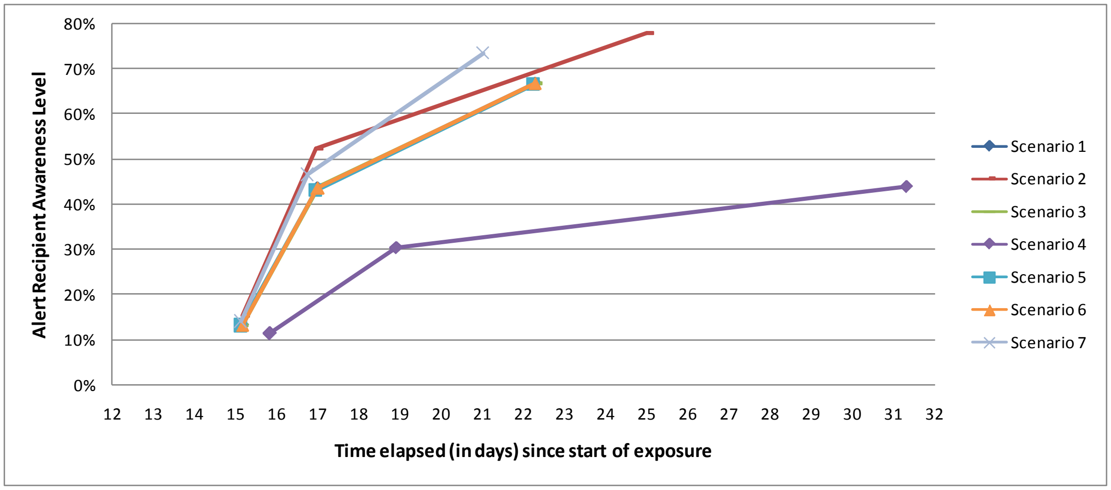

Figure 5: Alert Recipient Awareness Level Over Time for Experiment 1. Scenario 1: Base Case; Scenario 2: Decrease HR Levels in Hospitals by 50%; Scenario 3: Decrease HR Levels in LHDs by 50%; Scenario 4: Decrease Lab Resources by 50%; Scenario 5: Increase HR Levels in Hospitals by 50%; Scenario 6: Increase HR Levels in LHDs by 50%; Scenario 7: Increase Lab Resources by 50%

In the analysis of the NC PHIN system, primary areas of improvement are identified by potential bottlenecks in our system. As explained earlier, long queue times in a process followed by significantly shorter queue times in subsequent stages of the process are used to identify bottlenecks in the system. For this analysis the average queue waiting times provided insight into potential system bottlenecks. As indicated by Table 1, our data implies that the bottleneck in NC PHIN is primarily associated with the lab capacity. This is suggested by the long wait times in queue for the lab resource followed by subsequent processes with no queues. Furthermore, the lower utilization of other resources in the system indicate that the NC PHIN system has some level of capacity that is not being utilized which further supports our hypothesis that the lab may be the source of NCPHIN's bottleneck, limiting the effectiveness of other resources.

Our findings suggest that investments in improving overall system performance of NC PHIN should be aimed at improving lab capacity. Although other capacities may still be important, investing in priorities other than the bottleneck may not provide as much of a return on the investment in the overall system performance if the value of competing priorities are being limited by the bottleneck. Therefore, from an economic standpoint, since lab capacity is the resource that is constraining our system's capacity, it should be the primary area of focus in establishing investment priorities (e.g. funding or the allocation of resources) for improving the performance of the public health response system (NC PHIN).

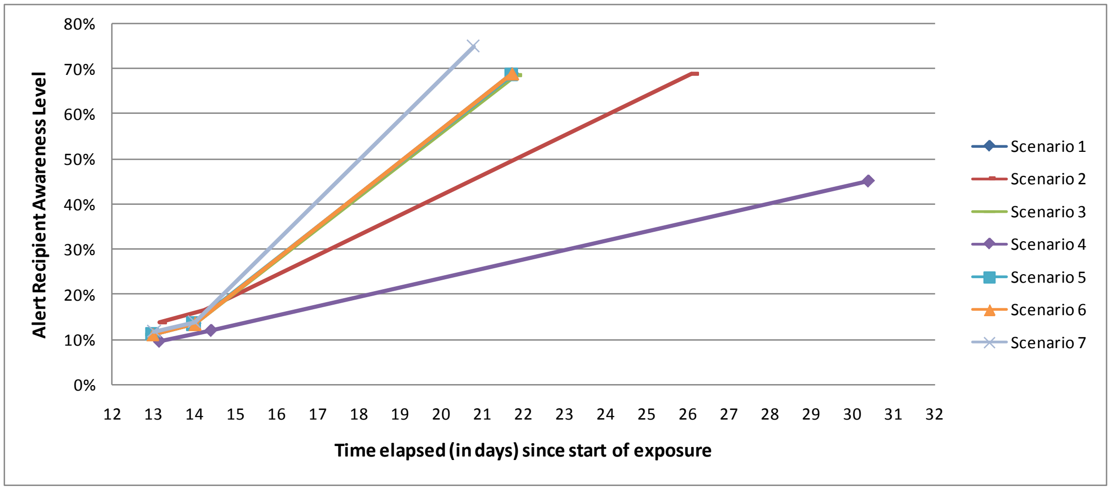

Figure 6: Alert Recipient Awareness Level Over Time for Experiment 5. Scenario 1: Base Case; Scenario 2: Decrease HR Levels in Hospitals by 50%; Scenario 3: Decrease HR Levels in LHDs by 50%; Scenario 4: Decrease Lab Resources by 50%; Scenario 5: Increase HR Levels in Hospitals by 50%; Scenario 6: Increase HR Levels in LHDs by 50%; Scenario 7: Increase Lab Resources by 50%

Table 1: Resource Utilization and Queue Waiting Time (in days) Data from Experiments 1 & 5

| **Experiment #** | **Scenario Name** | **Lab (Lab Resources) Utilization** | **LHD Personnel (LHD HR Level) Utilization** | **Physician (Hospital HR Level) Utilization** | **Preliminary Clinical Diagnosis - Queue Waiting Time** | **Samples Await Lab Diagnosis - Queue Waiting Time** | **Ordering Physician Documents Data on Green Card - Queue Waiting Time** | **LHD Personnel Manually Enters Data - Queue Waiting Time** |
|---|---|---|---|---|---|---|---|---|
| 1 | Base Case | 0.511 | 0.368 | 0.411 | 0.091 | 0.979 | 0.074 | 0.05 |
| 1 | Decrease HR Levels in Hospitals by 50% | 0.404 | 0.295 | 0.651 | 3.776 | 1.327 | 2.722 | 0.001 |
| 1 | Decrease HR Levels in LHDs by 50% | 0.43 | 0.618 | 0.344 | 0.082 | 0.992 | 0.068 | 4.883 |
| 1 | Decrease Lab Resources by 50% | 0.692 | 0.263 | 0.292 | 0.001 | 11.806 | 0 | 0 |
| 1 | Increase HR Levels in Hospitals by 50% | 0.512 | 0.371 | 0.272 | 0.001 | 0.989 | 0.001 | 0.056 |
| 1 | Increase HR Levels in LHDs by 50% | 0.511 | 0.248 | 0.41 | 0.088 | 0.981 | 0.071 | 0 |
| 1 | Increase Lab Resources by 50% | 0.351 | 0.375 | 0.418 | 0.2 | 0.012 | 0.155 | 0.07 |
| 5 | Base Case | 0.507 | 0.374 | 0.415 | 0.103 | 0.743 | 0.078 | 0.051 |
| 5 | Decrease HR Levels in Hospitals by 50% | 0.396 | 0.295 | 0.646 | 3.359 | 1.449 | 2.891 | 0.002 |
| 5 | Decrease HR Levels in LHDs by 50% | 0.42 | 0.622 | 0.342 | 0.097 | 0.768 | 0.075 | 5.284 |
| 5 | Decrease Lab Resources by 50% | 0.688 | 0.265 | 0.291 | 0.001 | 11.09 | 0 | 0 |
| 5 | Increase HR Levels in Hospitals by 50% | 0.504 | 0.374 | 0.277 | 0.002 | 0.753 | 0.001 | 0.062 |
| 5 | Increase HR Levels in LHDs by 50% | 0.505 | 0.249 | 0.413 | 0.107 | 0.729 | 0.079 | 0.001 |
| 5 | Increase Lab Resources by 50% | 0.341 | 0.375 | 0.416 | 0.177 | 0.006 | 0.137 | 0.067 |

## 6 CONCLUSIONS AND FUTURE WORK

While many would assume that investments in IT capacity would have the biggest impact on the capacity and performance of an information network such as NC PHIN our findings suggest otherwise. Limited capacity of other, more tangible resources in an information network can have huge impacts on other resources in the system. Based on our analysis, investments in lab capacity would have the most significant impact on the performance and capacity of NC PHIN during a state-wide E.coli outbreak. We determined this by identifying the resource that was limiting the overall capacity of NC PHIN based on queue wait times and resource utilization. The findings from our simulation also highlight the fact that the existence of capacity doesn't imply that the capacity is being fully utilized. Bottlenecks in the upstream stages of a process limit the utilization (and realized capacity) of subsequent resources. By identifying the bottlenecks of the system, our analysis can be used to provide public health stakeholders with a more knowledgeable understanding of where the inefficiencies and potential opportunities for improvement exist within their public health infrastructure.

Given the findings and challenges presented in this paper, there are significant opportunities for future research. Considering that the government has taken an all-hazards approach to emergency preparedness and response (Levi et al. 2008), we recommend future research focus on developing flexible, yet valid, measurements and methodologies that can measure the performance of an all-hazards emergency preparedness and response system. As suggested throughout this paper, more attention should be dedicated to ensuring that evaluation measures provide a way to articulate the quantitative value of emergency preparedness and response systems and investments. Within this context, priority should be given to approaches that capture and articulate the value of IT investments and other less tangible aspects of emergency preparedness and response. The methodologies extended in this paper also support the potential for the fields of operations research and systems engineering to provide a “toolbox” of methodologies and techniques that have the potential to provide very promising solutions to some of public health’s most pressing issues.

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## A APPENDIX

Input parameters for the simulation are provided.

Entities

| Entity Module Name | Entity | Arrivals | Entities Per Arrival | Logic | Data Source |
|---|---|---|---|---|---|
| Create Petting Zoo Visitors | Petting Zoo Visitors | Constant Arrivals Each Day | 6 | An average of 6 individuals became sick per day | Final Report |
| LHD Initiated Alert | LHD Alert Recipients | One time arrival | 100 | 100 alert recipients to represent the 100 counties (the vulnerable population) | Interviews |
| SHD Initiated Alert | SHD Alert Recipients | One time arrival | 100 | 100 alert recipients to represent the 100 counties (the vulnerable population) | Interviews |
| Final Alert | Final Alert Recipients | One time arrival | 100 | 100 alert recipients to represent the 100 counties (the vulnerable population) | Interviews |

Entity Attributes

| Entity Attribute Module Name | Logic | Data Source |
|---|---|---|
| Assign County | Petting Zoo Visitors are assigned to one of the 23 counties based on distribution of cases reported by each county | Final Report |
| High Priority Counties | Petting Zoo Visitors are assigned a high priority to use resources based on their reporting timeliness | NETSS Data |
| Medium Priority Counties | Petting Zoo Visitors are assigned a medium priority to use resources based on their reporting timeliness | NETSS Data |
| Lower Priority Counties | Petting Zoo Visitors are assigned a low priority to use resources based on their reporting timeliness | NETSS Data |
| Assign HUS | Petting Zoo Visitors are assigned with HUS based on percentage of cases reported as having HUS | Final Report |

Resources

| Resource Module Name | Resource | Action | Distribution | Unit | Distribution Data Source |
|---|---|---|---|---|---|
| Symptoms Reported to NCDETECT | n/a | Delay | TRIA(1, 6, 12) | Hours | Interviews |
| Symptoms Diagnosed and Samples Collected | Physician | Seize Delay Release | TRIA(1, 3, 8) | Hours | Interviews |
| Samples Await Lab Diagnosis | Lab | Seize Delay Release | TRIA(1.5, 4, 8) | Days | Interviews |
| Ordering Physician Documents Data on Green Card | Physician | Seize Delay Release | TRIA(1, 24, 72) | Hours | Interviews |
| LHD Manually Enters Data on NCEDSS | LHD Personnel | Seize Delay Release | TRIA(1, 24, 72) | Hours | Interviews |

Variables

| Stage of Process | Random Variable Module Name | Distribution | Units | Distribution Data Source |
|---|---|---|---|---|
| Reporting of Threat | Person Becomes Ill | TRIA( 2 , 3.5 , 5 ) | Days | CDC Website |
| Reporting of Threat | Time to Seek Treatment Delay | TRIA(1,3, 4) | Days | CDC Website |
| Reporting of Threat | Person Seeks Help By Reporting Symptoms | TRIA( 2 , 6, 12) | Hours | Interviews |
| Routine Surveillance | SHD is Notified Of Confirmed Case | TRIA( 4, 24, 48 ) | Hours | Interviews |
| Routine Surveillance | LHD is Notified of Confirmed Case | TRIA( 4, 24, 48) | Hours | Interviews |
| Routine Surveillance | Physician Notifies LHD of Case | TRIA( 1 , 24 , 48 ) | Hours | Interviews |
| Routine Surveillance | LHD Receives Green Card | TRIA( 1, 2, 4) | Days | Interviews |
| Routine Surveillance | SHD Receives Green Card | TRIA( 1 , 3 , 5) | Days | Interviews |
| Routine Surveillance | SHD Documents Case in NETSS | TRIA( .5, 2, 5) | Days | Interviews |
| Routine Surveillance | Documentation Delay | TRIA( 1, 2, 2.5 ) | Days | NETSS Data & Final Report |
| Confirmation of Threat | LHD Confirmation of Threat | TRIA( .5 , 4 , 24 ) | Hours | Interviews |
| Confirmation of Threat | SHD Confirmation of Threat | TRIA( 1, 4 , 24 ) | Hours | Interviews |
| Threat Notification and Dissemination of Information | Notify through NCHAN | TRIA( .0167 , 2 , 48 ) | Hours | NCHAN Data |
| Threat Notification and Dissemination of Information | Notify Through Non-NCHAN Source | TRIA( .16, 2 , 72 ) | Hours | Interviews |
| Implementation of Control Measures | Active Surveillance Begins | TRIA( 1, 5 , 24) | Hours | Interviews |
| Implementation of Control Measures | Epi Investigation to Identify Exposure and Implement Control Measures | TRIA( 13, 14 , 15 ) | Days | Interviews & Final Report |

Decisions

| Decision Module Name | Type | Percent True | Condition | Logic |
|---|---|---|---|---|
| Exposure Not Controlled? | 2-way by Condition | n/a | Global Variable "Exposure Identifier" <= "1" | Once exposure is identified, "Exposure Identifier" == "2". When the simulation starts "Exposure Identifier" == "1" so until the exposure is identified, Petting Zoo Visitors will be exposed. |
| Person Contaminated with E.coli? | 2-way by Chance | 72 | n/a | Throughout the simulation 150 Petting Zoo Visitors are created. 150*.72= 108 which is the total number of cases. |
| Assign Resource Priority | N-way by Condition | n/a | Attribute "Priority" = "High(1), Medium (2) or Low (3)" (based on Attribute "County") | Counties were assigned priorities based on their reporting timeliness |
| HUS Case? | 2-way by Chance | 14 | n/a | % of cases diagnosed with HUS |
| Lab Confirmed Case of E.coli? | 2-way by Chance | 37.96 | n/a | % of cases with lab confirmed diagnosis of E.coli |
| Case Count by County | N-way by Condition | n/a | Attribute "County" == "Respective County Number (1-23)" | Assigns cases to their respective counties based on their county attribute. Case counts for each county are recorded in their respective county queues which represent the local awareness for each county |
| PH Threat Detected by LHD or SHD? | 2-way by Condition | n/a | Global Variable "Detection Trigger" <= "23" | Determines whether LHD or SHD detects threat based on county attribute number. LHD's are numbered 1-23 and the SHD is 24. |
| Statewide PH Threat? | 2-way by Condition | n/a | Number of state cases >= 6 | At the time of the first alert, the SHD had received knowledge of 6 cases |
| Recipient receives information from NCHAN | 2-way by Chance | 91 | n/a | Estimated % of counties represented on NCHAN in 2004 |
| Recipient receives information nonNCHAN source | 2-way by Chance | 80 | n/a | Estimated % of counties represented on non-NCHAN sources of communication in 2004 |

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