

Quarantine Utility Associated with Supplying Area Residents (QUASAR)

Mobeen Vaid, Matthew Nilles, Kevin Gallahan, Katarazyna Domagala, *Students, George Mason University.* Andrew Loerch, *Faculty Advisors.* Clement McGowan, Yasmin Amin *Sponsor (NOBLIS Corporation)*

***Abstract—* The purpose of this study is to evaluate resource management and distribution in the event of a Category A (as defined by the Center for Disease Control) biological contamination that results in a regional quarantine of the population. The study focuses on the implementation of a system that will minimize the contact rate of affected individuals while ensuring that quarantined individuals receive critical medication as well as a sufficient supply of food over a period of at least thirty days. After conducting research and evaluation of the current National Response Plan, design alternatives were formulated. Alternatives include utilizing distribution centers as a means of resource distribution, standard door-to-door delivery, and a combination of the two that seeks to determine an optimal supply distribution. A successful implementation of the aforementioned alternatives is designed to result in a robust delivery system with rapid deployment. A combination of queuing models, max flow models, and a systems dynamic model are used to determine the favorable design alternative.**

I. INTRODUCTION

THE current state of world affairs presents a hostile environment towards many American interests. Some enemies are becoming technologically advanced and one day might pose a significant threat in the form of biological weapons. This may arise as a tactic in warfare or terrorism. In the event that a Category A biological agent naturally or intentionally contaminates a large number of civilians on American soil, a multitude of systems, agencies, and policies must be deployed. As defined by the Center for Disease Control, a Category A biological agent can be easily disseminated or transmitted from person to person, result in high mortality rates and have the potential for major public health impact, might cause public panic and social disruption, and require special action for public health preparedness. Examples are small pox, botulism, ebola, and marburg. Simulations show that mass quarantine might be the most effective tool for reducing the loss of life and depletion of resources [9]. Minimal attention has been paid to the logistical support systems that would be required during quarantine.

This paper presents a comprehensive food and critical medication distribution system in the event of a Category A biological agent contamination on American soil. The system, when properly implemented, will provide a robust distribution system which will minimize casualties and cost. The system will also include secondary services such as triage and transportation for individuals showing indications of emerging infection. A detailed description of the QUASAR system is presented; its concept of operations and functional and physical architectures are also presented. A simulation and analysis of the implementation of the QUASAR system has been carried out and is also presented.

II. SYSTEM DESCRIPTION

A. Major Assumptions

The following assumptions are made to establish the scope of our effort. Major infrastructure services will remain operational (water, electricity, gas, etc). An external government agency will be tasked with primarily controlling the quarantine. The incident is isolated to a small portion of the country. All existing Federal entities will continue to function after a major biological contamination. All major resources and their providers will not be deterred by the thought of working in or with a quarantine environment. The stated functionality of all government agencies (FEMA, National Incident Management System, etc) is as expected.

B. System Overview

The Quarantine Utility Associated with Supplying Area Residents (QUASAR) will be brought into use during varying levels of quarantine resulting from natural or intentional mass contamination of a Category A biological threat. The circumstances for deployment include instances when traditional venues for supplying civilians will not be operational, but when the major infrastructure services continue to function at nominal levels. The system's primary service is to provide critical food and prescription medicine to residences spread across varying geographical areas. Secondary services include triage and transportation for individuals showing indications of emerging infection. This system will be integrated into the National Incident Management System (NIMS) on all levels, relying on existing entities and providing new resources. The external influences include various government agencies and policies at the Federal, State, tribal, and local levels, as well as the

private sector and non-governmental organizations. The systems period of operation is the thirty-day period beginning close to the response and recovery phase of a contamination.

C. External Systems

To define the boundaries of the system, a diagram that outlines all of the external resource providers is presented (Fig. 1). The QUASAR system interacts with four other major resource providers that are also fully integrated into the National Incident Management System: purchased/donated food services, general facilities and food acquisition, security equipment and personnel, and volunteers and other resources.

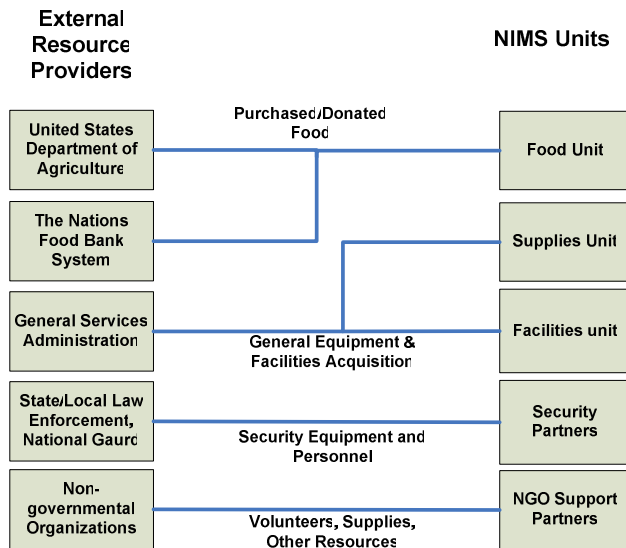


Figure 1: External Resource Providers Diagram

D. Functional Architecture

The QUASAR system is composed of five key functions. These include system management, resource distribution, user management, security, and other auxiliary functions. Figure 2 shows a diagram with resource distribution’s most important inputs, outputs and triggers. The system management includes the integration of NIMS management as well as resource management. Resource distribution is decomposed into distribution services, door-to-door delivery, and special needs deliveries (Fig. 2). Provide User Management is broken down into Provide User Tracking, Provide User Verification, and Collect User Feedback. This shows that the system will keep track of who receives supplies and that the correct persons received the proper supplies. The main two components of security include static defense and incident mitigation. Security will be deployed at the state and local levels initially, but the National Guard can be used to augment and reinforce security operations. The primary auxiliary functions of the system include triage, casualty transportation, and community outreach.

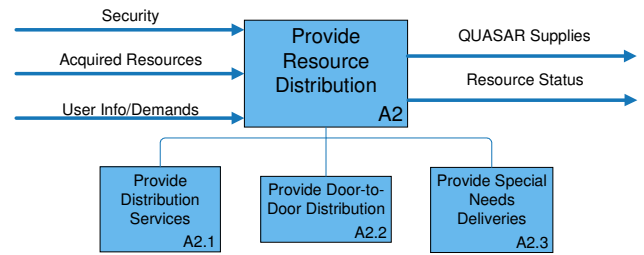


Figure 2: Functional Architecture for Resource Distribution

E. Physical Architecture

The generic physical architecture of the QUASAR System (Fig. 3) shows how the system will be organized. The physical components correspond to the mechanisms in the functional architecture. That is to say that the physical components perform the functions shown and described in the functional architecture.

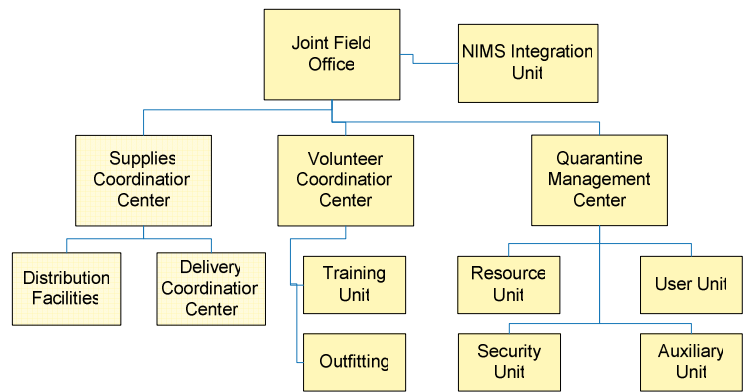


Figure 3: Generic Physical Architecture

III. DESIGN ALTERNATIVES

A top level look at the external systems interfacing with the QUASAR reveal the affected quarantine population, NIMS acting as an interface to the rest of the government, and Non-Governmental Organizations as the major mechanisms. Functionally, this system provides self management of resources while managing transactions with NIMS, management over all those using the system, resource distribution capabilities, security integration, and a broad capacity for supporting secondary systems. These functions are carried out physically by three major mechanisms: a Volunteer Coordination Center, a Quarantine Management Center, and a Supply Coordination Center. Three alternatives have been developed which capture different levels of cost, deployment times, resource requirements, reliance on external entities, maximum flow, reliability, security, effectiveness, and efficiency. These alternatives represent a range of problem solutions while staying feasible based on current knowledge, satisfying

system requirements, and being detailed enough to undergo thorough modeling and simulation.

The three alternatives are detailed below:

A. Resource Distribution Centers

After the quarantine is in effect, distribution centers will be set up to supply civilians with the needed supplies. Specifically, food will be made available to all for little to no cost. The requirement for the system is to provide all quarantined civilians with the proper amount of nutrition. This leads to the need for food to be available to people for little to no cost. For example, because all non-critical infrastructure businesses will be shut down, the citizens who live “pay check to pay check” need to be provided for. There will be a multitude of resource centers (Fig. 4) being used for the distribution of goods in the affected area. The primary distribution centers will be grocery stores. This is for a number of logistical reasons that include but are not limited to: stores are all ready geographically distributed according to population density, they are generally large parking areas with significant amounts of space, inherent commercial food networks are in place, and they are in known locations. Also, many grocery stores are located in shopping centers that would enable dynamic temporary warehouses to be set up.

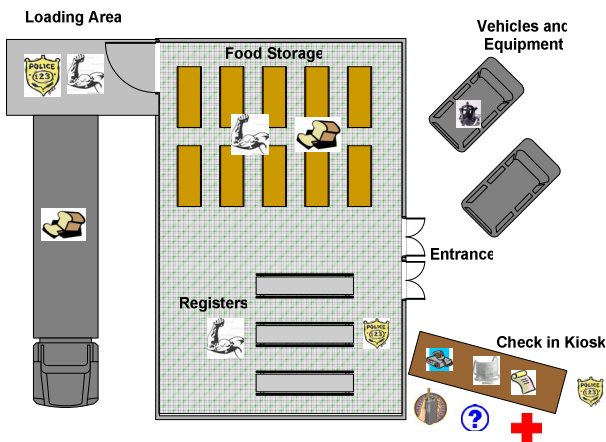


Figure 4: Physical layout of a Distribution Center

B. Door-to-Door Delivery

In this alternative, all supplies are delivered door-to-door (Fig. 5). The U.S. Postal System, FedEx, United Parcel Service (UPS), and other similar organizations will be used to distribute goods. System personnel, non-governmental organizations, and relief personnel will supplement these organizations. The Supply Coordination Center along with the American Red Cross will be heavily involved in this effort.

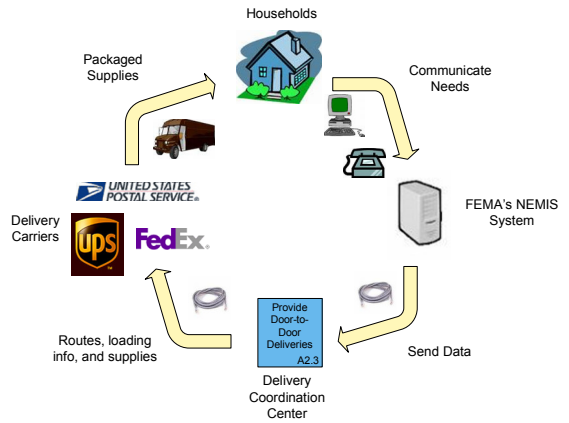


Figure 5: Basic Flow Chart for Door-to-Door Delivery

C. Combination

A combination of distribution centers with door-to-door delivery could prove to be the most promising. For example, during the initial outbreak of a disease, a door-to-door delivery system could be implemented to keep the contact rate to a minimum. After a certain period of time, the can then transition over to distribution centers. All will depend upon the results of our analysis.

IV. VALUE HIERARCHY

To elicit the value hierarchy from the subject matter experts (SME) the team coordinated a face-to-face meeting with them. The team used a documented brainstorming technique, affinity diagrams [7], which are designed to stimulate creativity and completeness. Each value in the value hierarchy was deemed to be at least preferentially independent.

The value hierarchy is diagrammed in Figure 6 below:

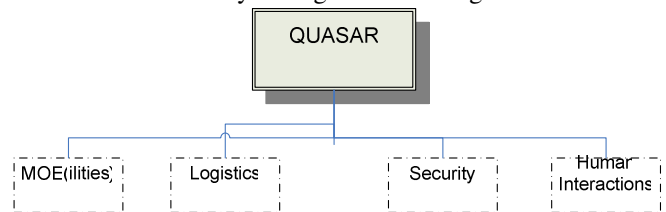


Figure 6: Top level of the value hierarchy

MOE (measures of effectiveness) consists of the adaptability of the system, the availability, the reliability of the system, and the lives lost. Logistics refers to the transactions of supplies, the usage of current plans, communication with the public, and disease tracking. Security refers to the security level of the supplies and the system employees. Human Interactions refers to the triage system implemented and the human resources available to the civilians.

Weights will be elicited from subject matter experts once all outputs of the modeling are completed and the ranges of the output values are established. This will result in the weights being a function of the range of variation. The utility function is formed which helps determine the desirability of the design alternatives. The Table below (Table 1) shows the details of each value and its respective

function associated in the utility function. The *Direction* describes whether the function is increasing or decreasing; if a low value is preferred, the function is decreasing. Indices are taken from their respective value hierarchy categories: M_i for Measures of effectiveness, L_i for logistics, S_i for security, H_i for Human Interactions.

Value	Indices	Direction	Bottom Level Weights
Adaptability	M_1	Increasing	W_{M_1}
Availability	M_2	Increasing	W_{M_2}
Reliability/Maintainability	M_3	Increasing	W_{M_3}
Lives Lost	M_4	Decreasing	W_{M_4}
Optimal Location	L_1	Decreasing	W_{L_1}
Transactions of supplies/Delivery	L_2	Increasing	W_{L_2}
Usage of current Plans/Systems/Equipment	L_3	Increasing	W_{L_3}
Government/Public Communication	L_4	Increasing	W_{L_4}
Disease Tracking	L_5	Increasing	W_{L_5}
Supplies/ Equipment	S_1	Increasing	W_{S_1}
System Employees	S_2	Decreasing	W_{S_2}
Triage System	H_1	Increasing	W_{H_1}
Civilian Human Resources	H_2	Increasing	W_{H_2}

Table 1: Utility Function Variables and Directions

The subsequent utility functions for the top level and the bottom level are shown below (Eq. 1 & 2)

$$U_{SDSQC} = w_M v_M + w_L v_L + w_S v_S + w_H v_H$$

Equation 1: Top Level Utility Function

$$U_{SDSQC} = w_{M_1} v_{M_1} + w_{M_2} v_{M_2} + w_{M_3} v_{M_3} + w_{M_4} v_{M_4} + w_{L_1} v_{L_1} + w_{L_2} v_{L_2} + w_{L_3} v_{L_3} + w_{L_4} v_{L_4} + w_{L_5} v_{L_5} + w_{S_1} v_{S_1} + w_{S_2} v_{S_2} + w_{H_1} v_{H_1} + w_{H_2} v_{H_2}$$

Equation 2: Top Level Utility Function

All of the aspects of the above components in the utility function were represented in two main simulation models and four analytical models. These models give a quantitative output for the utility values to help determine the preferred alternative.

V. MODELING AND ANALYSIS

In order to analyze each alternative based on the value hierarchy, a total of six models were developed to cover the majority of metrics. The models share some common inputs,

and accept outputs from the other models as indicated in the information flow diagram below (Figure 6). The dependencies shown only reflect the major relationships.

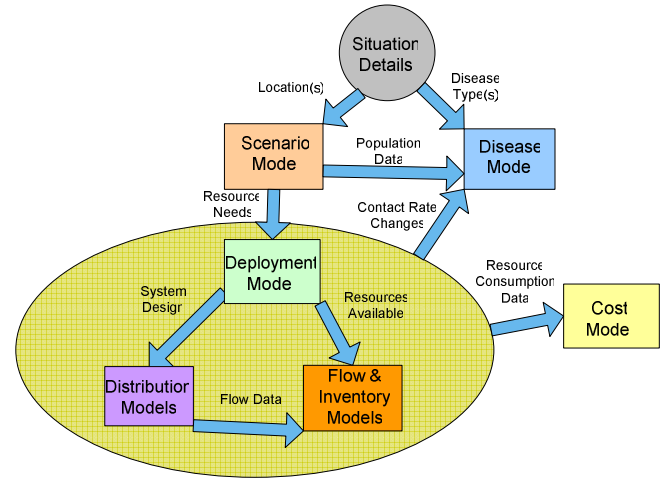


Figure 6: Primary Model Inter-dependency

Scenario Development: This initial analytical model sets the stage for the location, type of disease, and available resource constraints. This is an analytical model that is based on real world population and facility data gained from the U.S. Census and address databases. The output from this model is critical for all other models and so extra care was taken to determine accurate information. The second part of this analytical model uses a set of pre-determined scenarios for subject matter experts to judge each design alternative's performance in reference each scenario. Scenarios include but are not limited to: Earthquake, hurricane, major flood, etc). The output is primarily used to quantify each design alternative's *Adaptability*, which is part of the utility function.

Distribution Models (queuing): Several simulation models were created in Rockwell's Software's Arena to model different approaches towards distributing goods. Arrival rates were obtained from real world population and location data, while the times to accomplish tasks were gained from adapting data from similar studies into large-scale distribution centers. U.S. Postal data was also used specifically for the door-to-door alternative.

Disease Propagation Model: This is a simulation model provided to us through Noblis. The model was developed in I-Think software and uses an excel spreadsheet as input. The purpose of the model is to simulate the number of casualties over time from the outbreak of contagious disease. The variables that were manipulated include disease type, initial infected population, several contact rates based on population type, time until a contact rate change, and total population.

Deployment Model: This analytical model captures the total time taken to gather, train, outfit, and distribute system

personnel, equipment, facilities, and resources. This “deployment time” is critical to early reduction of the contact rate by allowing for a quarantine to be established earlier.

Inventory/Maximum Flow Model: This is a blend of an analytical and queuing model. The model’s purpose is to investigate how resources are organized, packaged and distributed at the main Supply Coordination Center. This model, constrained by the supplies required by the quarantine area and available through external providers, establishes a reliable inventory system for QUASAR.

Cost analysis: The final model involves a broad analysis of the total cost of running QUASAR. It attempts to include total dollars, lost productivity, and resource utilization time.

CONCLUSION

QUASAR provides a means to successfully implement a quarantine of civilians after a biological attack. The logistical details of supplying an affected population are detailed and feasible. Preliminary modeling efforts lead us to believe that the design alternative of delivering goods door-to-door is unfeasible for a large enough population. Finalized results will determine if this is accurate, and if so, where the “break point” is. Analysis of the third design alternative, a combination of door-to-door delivery and distribution centers, will be constrained by the above mentioned result.

ACKNOWLEDGMENT

Noblis is a nonprofit, scientific research and systems engineering corporation that operates in the public interest. Employing approximately 800 individuals, Noblis focuses on non-defense operations, while The Mitre Corporation, which broke away in 1996, is a separate entity working for the DOD and FAA. Noblis primarily works for the government; however they also have public clientele in the areas of health care, the environment, biotechnology, energy, information services, law enforcement, telecommunications, and transportation. Following their mission to use information and knowledge to solve real world problems, Noblis benefits its clients with cost effective and unbiased solutions. Noblis truly believes in sharing knowledge with the public, while achieving the highest standards of excellence in all fields of work. Their vision can not be said any better than as follows:

To be a great company – a national resource that has earned its reputation by making significant contributions to addressing important issues – contributions that make a different in peoples lives.

REFERENCES

- [1] Bioterrorism and Emerging Infections Education, <http://www.bioterrorism.uab.edu/CategoryA/Smallpox/summary.asp>
- [2] Public Health Training Network, <http://www.phppo.cdc.gov/phtn/antibiotic3/>
- [3] National Immunization Program, http://www.cdc.gov/nip/publications/pink/def_pink_full.htmE. H.
- [4] Agency for Healthcare Research and Quality, <http://www.ahrq.gov/research/cbmprophyl/cbmgpde1.htm#Overview> C.
- [5] Centers for Disease Control and Prevention
- [6] Noblis, www.noblis.org
- [7] Nancy R. Tague’s The Quality Toolbox, Second Edition, ASQ Quality Press, 2004, pages 96-99.
- [8] Federal and State Quarantine and Isolation Authority, Kathleen S. Swendiman and Jennifer K. Elsea, Legislative Attorneys, American Law Division
- [9] Effects of behavioral changes in a smallpox attack model, S. Del Valle, H. Hethcote, J.M. Hyman, C. Castillo-Chavez