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Decision Support to Improve Service Quality in Demand Surge Situations

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Efficient supply chains should be responsive to demand surges and supply disruptions resulting from internal and external vulnerabilities. Worst case demand surges and supply disruptions are very low probability occurrences; but the magnitude of the impact can be enormous. Hurricane Katrina provided an example of the magnitude of coordination required in responding to a disaster. Disaster response in such a situation requires a scalable information supply chain. Scalability hinges on innovative IT solutions for communication and collaboration. It also depends on collaborative arrangements with other disaster relief agencies and corporate collaborators. These collaborative arrangements require prior planning to design and test the information exchange/sharing processes. While extant IS research establishes the importance of information structure in decision-making (Choudhury and Sampler 1997) in terms of knowledge and time specificity, there is limited understanding of how collaborative arrangements and resource allocation interact in demand surge contexts.

IT can be a great enabler in enhancing our ability to cope with disaster events. It can also increase situational awareness among decision-makers and enhance coordination through efficient communications. When Decision Support is also provided, IT can greatly enhance resource mobilization, allocation and coordination efforts.

The proposed research takes an inter-disciplinary approach to addressing the cognitive challenges faced by decision-makers during disaster events. The objective is to develop models and systems to support decision making in the demand surge context.

Research Context

The context for the research stems from the supply chain related issues pertaining to pandemic flu planning. The 20th century witnessed 3 influenza pandemics, the most severe one resulting in about 500,000 deaths in the United States. A modern day pandemic in the US could infect between 75 and 90 million people, and cause between 100,000 and 2 million deaths (Eakin 2005). Once the pandemic sets in it is expected to spread rapidly, resulting in a demand surge for scarce healthcare resources such as beds, vaccines, medicines, nursing staff and doctors. In order to combat the epidemic therefore, it becomes imperative to manage these scarce resources and ensure their availability to those that need it the most in a timely manner.

Surge capacity is a health care system's ability to expand quickly beyond normal services to meet an increased demand. The healthcare system can improve surge capacity by either maintaining redundant capacity in centrally located stockpiles, and/or reallocating and redirecting existing capacity through mutual aid at the regional level. The choice between use of redundant capacity and mutual aid at the regional and local level is not an obvious one, and will depend on several factors including: (a) coordination, communication, delay and transportation costs, (b) budget constraints at the regional and local level, (c) accurate and real-time availability of information on resource excesses and shortages, (d) complex resource constraints such as bundling, (e) required service quality, (f) and the level of cooperation between participating agencies.

These factors lead us to the following research questions:

1. How do collaborative arrangement structures (i.e., social networks) interact with resource allocation decisions in demand surge scenarios?
2. What bearing does the choice of resource allocation policy and collaborative arrangements have on service quality?
3. How can real-time communications information be utilized to enhance decision support capabilities to deal with an evolving demand surge problem?

Theoretical Framework

The theoretical basis for the research is drawn from the services science area. The new discipline of Services Science is an inter-disciplinary approach that applies scientific, management and engineering disciplines to tasks that one party performs for and with another party, to transform some state, such as material goods, information goods or organization (Spohrer and Maglio 2005). Creating and delivering a business service requires efficient and effective capacity planning (queues and demand), service encounter (skilled labor), service quality (Mendelson and Whang 1991; Gupta et al, 1996), resource planning, managing demand fluctuations, and managing information (Dietrich 2006).

These requirements are even more pronounced in an information-driven, customer centric, productivity focused and time-critical area such as healthcare. In order to avoid costs associated with underutilization of resources, organizations only prepare for the "average" demand scenario. In the event of a healthcare emergency leading to mass casualties, such as an epidemic, the demand surge would far exceed normal demand fluctuations, and healthcare resources will be stretched to their limit. Services Science therefore provides an appropriate theoretical framework.

Data and Methods

Our data collection phase is nearly complete. We are using data provided by the CDC, Maricopa Department of Public Health, and the Red Cross.

We are taking a modeling and simulation approach, and draw from the Operations Research and Economics literature. We use utility-based constrained optimization methods for resource allocation, and extend this framework to study resource bundles. We adapt the *lateral transshipments* literature in OR to study mutual aid in the disaster context. Social Network Analysis provides a framework to model the level of mutual aid based on inter-organizational ties among mutual aid entities. Queuing theory methods are used to study the dependence of service quality on server configuration, arrival rates and queue capacities. The concept of delayed decision making or *postponement* is used to determine how much decisions regarding resource allocations can be delayed so as to gain more information on the requirements, thereby reducing risk and uncertainty costs.

We are also developing a multi-agent simulation environment in Repast. We propose using this environment to validate our model. It will also provide decision makers with an interactive environment to evaluate decision alternatives in the context of an on-going large-scale disaster.

Preliminary Findings

A modeling and simulation approach to evaluate an autonomic computing based utility optimization approach for resource allocation was developed as an early step for this research (Arora et al. 2006). The simulation environment utilized the autonomic computing paradigm and made use of an open source multi-agent environment (Repast) for modeling population specific behavioral profiles. While the basic disease outbreak conditions were parametrically defined using a standard Susceptible-Exposed-Infected-Recovered (SEIR) framework, the multi-agent model enabled the modeling of the spatial aspects of the outbreak region, resource availability-attribute-behaviors, and population characteristics.

In extending this line of work, a utility-based constrained optimization model to evaluate the allocation trade-off between centrally located stockpiles and mutual aid for antiviral distribution during an Influenza pandemic was recently developed (Arora et al. 2007). To illustrate the decisional impacts of allocation, three different epidemic scenarios involving three regions in Arizona and California, with a total of 19 Counties were utilized (Arora et al. 2007). Using a cost structure based on inter-county distances and accessibility it was found that the current policy of pre-allocating resources to States may not be optimal under all circumstances. Delaying the decision of how much to allocate will provide greater flexibility in dealing with the epidemic, thereby providing a more optimal response. Since delayed decision making strongly hinges on the availability of accurate and timely data, the result also implies that investments in information gathering and coordination should be made as part of the pandemic response plan.

Proposed Research

Work is currently underway to extend this modeling approach to include Social Network measures. This will enable the exploration of whether network cohesion, centrality, and other characteristics specific to a geographical area impact mutual aid. Preliminary results are encouraging. The modeling approach will also be further extended to consider resource bundling issues. The bundling of resources presents a complex problem setting that can have a significant impact on how resource allocation decisions should be made in pandemic-like scenarios where relations between resources impose a high cognitive burden on decision makers. Finally, service quality in this context will be modeled using queuing theory and dynamic programming methods.

While this research focuses on the healthcare context, the results are by no means domain-specific, and will apply equally well to demand surges and supply disruptions in other kinds of supply chains. For instance, the results could be extended to an IT disaster scenario such as a network outage, and the problem of maintaining service quality while responding to such a disruption.

Research Timeline

Milestone	**Completion Date**
Proposal defense	May, 2007
Data collection	Complete
Constrained optimization problem setup	May, 2007 (80% complete)
Bundled resource constraints	July, 2007 (10% complete)
Lateral transshipments and service quality	September, 2007 (25% complete)
Social networks and mutual aid	November, 2007
Information constraints and decision support	February, 2008
Simulation environment	February, 2008 (50% complete)
Dissertation Defense	April, 2008

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