Design and Optimization of Agent-Based Emergency Supply Chains

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Networks provide the physical and information structure of systems for transporting all food, water, people, information and goods within our modern life. Emergency Management (EM) organizations need to have highly functioning logistics networks as key towards supporting and aiding affected populations in disasters or conflicts.

Optimization has made immense strides towards improving logistics costs and services. However, most optimization has been designed to operate in a centralized environment, while many systems actually operate in a decentralized way, with individuals making decisions that impact the entire system, especially in emergency management. EM operations can be linked with mobile computing, but new methods are needed to operate across the decentralized network.

We introduce research that explicitly integrates the decentralized decision-makers into the optimization of the entire supply chain by incorporating their behavior with mathematical models so as to improve the overall system outcomes. Specific research areas we study include:

1. The strategic design and management of a service network that will be operated by a set of decentralized agents, where agents may be high level entities such as governments, military branches, or non-governmental organizations (NGOs). Furthermore, we develop optimization techniques for making tactical level decisions in a network with decentralized agents as well as to design the mechanisms/incentives of the agents to achieve greater efficiency where the agents are assumed to be individual participants.

2. Control of information sharing as a mechanism to improve decentralized decisions. In this setting we assume that there is a centralized overseer who tries to maximize the performance of the overall system and that he influences the dynamic decisions of individual agents by controlling the information that is passed on to the agents on the overall system status, such as through mobile computing applications.

The methods we develop can be linked with mobile computing applications and sensing networks, as well as models of human behavior to improve robustness of the network. Our research can also include *evaluation and measurement* of the system through analytics, experiments, and analysis of secondary data, to understand characteristics leading to robust network, and how human interactions play a role in local optimization.

The result of this research will be innovative scientific technologies to incorporate *decentralized* agent decision making into network design and analysis, resulting in supply networks that can function in decentralized, disruptive environments. The advances will transform the performance not only of state and federal governments, but also private firms and non-governmental organizations (NGOs). To ensure relevance and impact, we have built connections with organizations including The American Red Cross, the Centers for Disease Control and Prevention, FEMA, USACE, The Home Depot, UNHCR, UN WFP, and others to solve supply chain problems form pre-event planning to post-event recovery.

1. Research

Our overarching objective is to determine *the right structure of the network and methods for its control, including the level of decentralization, information sharing, and incentives, so that the network is robust to disruptions and resilient when they occur.*

Our paper fits into the workshop themes of Information Sharing and Interoperability and addresses workshop subtopics such as resilience to attacks, frameworks for logistics information exchange, information challenges for dynamic crisis supply chains, and agent-based coordination technologies. Our research makes fundamental advances in linking optimization of agent-based supply chains with behaviorial models from game theory. We focus on systems that can be implemented with sharing of information through cyberinfrastructure and policies that design information flow to improve the overall supply chain performance in an emergency setting. We also analyze and quantify, theoretically and computationally, the effects of explicitly incorporating the agent behavior in strategic, tactical and operational decision-making.

1.1 Network Design and Control

Many large scale logistics networks operate as a collaboration by utilizing multiple fleets (for example fleets of trucks, trains, or ships) belonging to different agents or organizations. To realize the overall efficiency the agents need to agree on the design of the service network and the subset of the overall demand that should be satisfied, assign specific assets to cover the legs of the network and design a mechanism to allocate the total space, cost and benefit to the participating agents or organizations. In general, sustainable collaborations require mechanisms to govern membership rules and allocate costs and benefits in a fair way.

The mathematical tools most appropriate to understand these problems are obtained by uniting concepts of mathematical economics and game theory with that of algorithm design and optimization. Cooperative game theory (see [8] for an overview) studies the class of games in which selfish players form coalitions to obtain greater benefits , and ideas from duality theory in linear programming may be used to develop good algorithms [6], [7]. The contribution of our research is to provide a general framework for designing mechanisms that can be used to manage decentralized service networks by designing incentive mechanisms that also regulate the interaction among the agents, for example by determining prices at which the agents can exchange their resources.

Our initial results include modeling a centralized network design problem, approaches for solving this large scale and NP hard problem, one way of modeling behaviors mathematically and the resulting mechanisms for managing capacity exchange interactions among the agents (see [1], [2], [3], and [4]).

1.2 Information Flow and Sharing Mechanisms

In contrast to systems that have centralized control over multiple assets, there are systems with individual users who only have control over their own decisions such as which route to take or which facility to choose. However, the underlying networks may be designed and managed by a centralized planner. Furthermore, the centralized overseer may pass on information, predetermine rules and protocols for local action, charge for usage, or change the network structure temporarily to influence the users' decisions.

We study mechanisms such as information flow that can be utilized to influence the behavior of the selfish users. At the strategic and tactical levels, we study how to mathematically incorporate local user behavior in the centralized network design problems such as where to locate service facilities. We also show that the impact of failure to account for user behavior on the overall system performance is substantial. At the operational level, we propose mechanisms and incentives such as dynamically controlling information flow and temporarily changing the network structure so that the decentralized system achieves a socially optimal performance.

The motivation for the work proposed in this area is to address the challenges of locating facilities or building networks that will be accessed by decentralized individual users. Such situations may arise in managing drivers during an emergency evacuation or managing people who are deciding which facility to go to either to obtain supplies or obtain medical care after a disaster. Our initial work shows that more information is not always better for the overall system performance, which indicates more research is needed in order to determine where and how much information should be given (see [5]).

1.3 Emergency Supply Chain Applications

Our center has been extensively involved in working with organizations to design and improve their supply chains for effective emergency response. Past projects have spanned the timeline of disaster activities including policies, preplanning, tactical response, and recovery post-disaster. Specific examples include global prepositioning of inventory for CARE, UNHCR, and WFP; case studies on response efforts by The Home Depot and Waffle House for hurricanes and other disasters; supply chain design and interventions for influenza pandemic in Georgia and with the American Red Cross; and debris collection post-disaster with FEMA and USACE.

2. Research Team

The three investigators co-founded and co-direct the Humanitarian Logistics Center of Excellence in the Supply Chain and Logistics Institute at Georgia Tech. The mission of the center is to improve humanitarian response and ultimately the human condition by system transformation and organization effectiveness through education, outreach and solutions. More information about the center is available at http://humanitarian.gatech.edu including the conference proceedings of the center's event on improving humanitarian logistics in February 2009.

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Dr. Julie Swann is an Associate Professor in the School of ISyE at Georgia Tech with a Ph.D. in Industrial Engineering and Management Sciences from Northwestern University (2001). She has research expertise in managing demand in decentralized systems in the supply chain and healthcare policy. In 2002, she received the Doctoral Dissertation Award from the Council of Logistics Management, and in 2004 she was awarded an NSF CAREER grant.

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