

Modeling Emerging Coalitions in the context of Inter-organizational Networks: A Case Study of Humanitarian Coordination

Kang ZHAO, John YEN, Louis-Marie NGAMASSI, Carleen MAITLAND, and Andrea H. TAPIA

Abstract—Forming coalitions and working collaboratively are important means of inter-organizational coordination. During coordination activities, organization’s evaluation of candidate collaborative projects and subsequent decisions on forming coalitions are often influenced by the ideas of their peers in the inter-organizational network. Using humanitarian coordination as a case study, we propose a formal model for the emergence of coalitions in the context of inter-organizational networks. This model incorporates both the characteristics of organizations and the inter-organizational network as factors for network influence. It has been implemented in an agent-based simulation for the study of humanitarian coordination.

Index Terms—Emerging coalition, inter-organizational network, network influence, humanitarian coordination, agent-based model

1. INTRODUCTION

IN recent years, as the world has witnessed changing approaches to organizations working together, researchers have devoted considerable amount of time studying coordination [22][15]. Inter-organizational coordination entails developing strategies, determining objectives, planning, sharing information, the division of roles and responsibilities, and mobilizing resources. Coordination among organization is also seen as important strategies used by public, private, and nonprofit institutions to achieve both short-term and long-term organizational goals [15]. A better understanding of inter-organizational coordination may reveal ways to facilitate and improve coordination activities.

Just like individuals, organizations are also often embedded in networks, such as business partnership networks, supply chain networks or information exchange networks. Through those networks, organizations are often able to exert influence on each others’ decisions. In this paper, we will use humanitarian coordination as a case study for inter-organizational coordination and try to model the emergence of coalitions in the context of inter-organizational networks.

In the past a few years, the world has suffered from several major natural disasters, including the south Asian tsunami, hurricane Katrina and the Pakistani earthquake. Humanitarian relief efforts after these tragedies have highlighted the need

for greater levels of inter-organizational coordination among humanitarian organizations.

In the humanitarian assistance sector, the primary objective of inter-organizational coordination is to improve the efficiency and effectiveness of humanitarian response so that the response meets the needs of the affected population to the maximum extent possible [4][34]. Scholars have also identified and documented benefits of inter-organizational coordination in the humanitarian field, such as facilitating division of labor with other aid actors; supporting small, new non-governmental organizations (NGOs) by linking them to those with more experience; catalyzing activities which may require a critical mass to get them off the ground; identifying NGOs who may collaborate with donors; establishing guidelines for best practice and norms for proper conduct; acting as a reference point and analytical resource on sector wide issues; and providing support services requested by the membership [4][3][34][7].

One approach taken by humanitarian organizations has been to organize ‘coordination bodies,’ whose goals are to improve disaster relief efforts through greater coordination among its member organizations. These coordination bodies may be temporary, special initiatives, or permanent incorporated nonprofit organizations that facilitate coordination as their exclusive mission. The goal of our research is to understand how changes to the organizational designs of coordination bodies might affect their effectiveness, so that recommendations can be provided for efficient coordination among humanitarian organizations, which will eventually benefit disaster victims.

While coordination may consist of many types of activities, our research focuses on the process of collaborative project identification and coalition formation. This process is one of the core processes in affecting the eventual coordination outcome. It has been found that, despite the similarities and differences in the characteristics of coordination bodies, they all use collaborative projects as a major means of facilitating coordination between their member organizations, mostly NGOs [20][27]. The Information and Communication Technology (ICT) Skills Building Program of the ReliefTechNet¹ is an example of such projects. The goal of this project was to provide training on latest ICTs to staff members of humanitarian organizations. It aimed at helping NGOs serving developing countries to improve their response to emergency and enhance their organizational effectiveness with

Kang Zhao, John Yen, Louis-Marie Ngamassi, Carleen Maitland and Andrea H. Tapia are with College of Information Sciences and Technology, the Pennsylvania State University, University Park, PA 16802, USA. (Email: kangzhao@psu.edu, {jyen, Itchouakeu, cmailto, atapia}@ist.psu.edu)

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¹In this paper, pseudonyms of organizations are used to protect the confidentiality of these organizations.

the help of ICTs. This project was initially proposed by one organization in the coordination body ReliefTechNet, but was then developed with inputs and contributions from a coalition of more than ten different members.

It is also worth mentioning that, within coordination bodies, project identification and coalition formation occur in a network that does not have formal hierarchies. Each member is a representative of a 'home organization' and comes to the coordination body with priorities, resources and power that are in part determined by their 'real jobs'. Participation in the coordination body and subsequently the coalitions for collaborative projects that are identified is undertaken on a purely voluntary basis. Coordination bodies have no authority to impose their activities or agenda on its member organizations.

Therefore, in this coordination process, there is no organization that can command others to join a coalition or work on a specific project. Members of coordination bodies must come together to identify mutually beneficial projects that fulfill a variety of requirements, including overlapping with home organization agendas, having adequate resources and having long-term benefits, among many others. Collaborative projects and corresponding coalitions thus 'emerge' from the collective behaviors of individual organizations.

Our empirical study of humanitarian coordination behaviors has revealed that, the network of an organization influences the organization's evaluation of candidate collaborative projects and the subsequent decision-making on coalition formation. Factors such as who it has connections with, strength of ties and peer pressure all affect their attitudes towards a project [21]. Specifically, in this paper, we will try to model how peers from an organization's network influence its evaluations of candidate collaborative projects.

The rest of the paper is structured as follows: First, the research on agent-based coalition formation and social influence models is briefly reviewed. After the framework for modeling coalition formation is introduced, the formal model of network influence on project evaluation is proposed and a simple experiment with an agent-based model is illustrated. The paper ends with a conclusion and a discussion of the future research plan.

2. RELATED WORK

Computational simulations, especially agent-based models, have been widely used to study a variety of social and organizational phenomenon [9], because those models are capable of simulating organizational structures or patterns resulting from low-level interactions and decision-making of heterogeneous agents within complex systems [6]. However, as an important topic in inter-organizational coordination, coalition formation did not draw much attention from the study of these models, which often start from agent-based organizations or coalitions that have already been formed.

Research on agent-based coalition formation has been conducted mainly in the community of multi-agent systems and distributed artificial intelligence. A great amount of their research aims at forming multi-agent coalitions for collaborative

tasks. There are two popular approaches to form such task-oriented coalitions.

One approach is task or sub-task allocation [17][29][30]. Tasks or sub-tasks are allocated to agents who are able to or willing to accomplish them. The allocation of tasks can be done through top-down assignments in a hierarchical multi-agent environment [1] or through market-based bidding and contracting among self-interested agents [16][28].

The other popular approach is to divide the agents into groups using set covering or set partitioning algorithms, depending on whether overlapping coalitions are allowed. The goal is to find agent groups that have enough capabilities or resources to accomplish the given task, yet do not contain surplus members [14][29]. Agents are attracted to join in the group because they can get fair individual pay-offs by jointly working on the task [36].

The interplay between agent networks and agent-based coalition formation has also been studied, although there has been relatively little research on this topic. For example, set covering algorithms have been used to divide a network of agents into coalitions of bounded size [32]. However, a coalition must be a clique, i.e., an agent in a coalition must have direct network connections with all the other agents in the coalition. Study has also found that social network topology affects coalition formation outcomes. Scale-free networks outperform random and small-world networks in terms of coalition formation efficiency [11]. Interestingly, some coalition formation strategies in dynamic social networks may lead to the scale-free topology [12].

Meanwhile, in the research of agent-based systems, inter-agent influence is an important topic, because agents often influence others based on the influence they received from others [19]. Such influence has been used to the study agents' behavior or belief changes [13][24], the computing load of distributed multi-agent systems [18], etc. One of the popular ways to model inter-agent influence is based on similarity [8][25]. In these models, agents tend to interact with those who are more similar to themselves based on how much knowledge or how many attributes they have in common. Therefore, an agent is more likely to be influenced by similar peer agents. However, structures of the agent network are not reflected in these models.

From outside the agent research literature, we found the network-based model for social influence [10]. Models of this type describe how a network of interpersonal influences affects the process of opinion formation. Basically, individuals in the network take into considerations the opinions of their network neighbors and adjust their own accordingly. Influence in social networks is represented as an iterative process based on structural parameters of the network.

Nevertheless, the aforementioned social influence model focuses more on group stability and studies the dynamics of simple, sometimes binary, opinions on a single issue. It does not prescribe how the inter-agent influence is calculated. Also, the network-based model essentially takes the centralized approach and cannot be directly applied to distributed agent-based models.

On the other hand, coalition decision processes in human-

itarian coordination involve dynamic, iterative and deliberate evaluations of multiple candidate collaborative projects. Also, there are a lot of practical factors that will affect inter-organizational influence, such as size of an organization, geodesic distance, i.e., the length of the shortest path, between organizations, resources possessed by an organization, etc.

Therefore, to simulate coalition formation with the network influence on each individual organization's evaluation of projects in a network that does not have formal hierarchies, we will have to extend existing influence model.

3. PROPOSED APPROACH

3.1. The Basic Framework

We proposed a basic agent-based framework to study the emergence of coalitions and collaborative projects among organizations [35]. In the framework, organizations are modeled as heterogeneous and self-interested agents. Each organization varies in organization sizes, organization goals, available resources, networks, the ways of evaluating candidate collaborative projects, etc. Each agent will have an ordered to-do list consisting of potential projects, on which they would like to or have to collaborate with others.

We also formalize an interaction scheme to simulate the interactions among humanitarian organizations inside a coordination body. The scheme consists of two phases of interactions: group meetings and private discussions. In a group meeting, each agent will propose the project at the top of its to-do list, which is often the project that it wants to accomplish the most, to all the other agents. On the other hand, in private discussions, agents only interact with previously acquainted agents, i.e., organizations in their networks.

In both phases, organizations will evaluate received candidate collaborative projects based on various criteria of their own, such as whether the goal of the project matches the goal of the organization, the cost and benefit of the project, the feasibility of the project, etc. The outcome of the evaluation process is a priority score for each project. Due to the heterogeneous nature of organizations, different organizations may assign different scores to the same candidate project. Then organizations may add new projects with higher priority scores to its to-do list, remove projects with lower priority scores from the list, or re-evaluate and re-rank existing projects in the list.

After a few rounds of such inter-agent interactions in the network, a valid collaborative project may emerge when the following two criteria are met: First, it is supported by more than N_{min} agents in the multi-agent environment, i.e., more than N_{min} agents have this project on their to-do lists. In reality, the threshold value N_{min} often varies for different coordination bodies. It serves as one of the requirements for a project to be endorsed by a certain coordination body. It is often easier for a project to get recognized, receive external funding and thus be successfully implemented if it gets endorsed by a coordination body. When the number of supporters for a project does not reach the threshold, it is still possible that those organizations carry on with this project, although they may have to do that outside the coordination body without the

endorsement. Second, all the required resources for the project can be gathered from the contributions of its supporters. Those who support the emerged collaborative project are said to form a coalition for this project. Other agents that do not support the project are not required to join the coalition.

Our formal model of network influence in project evaluation is based on this framework.

3.2. Influence from Networks

Inspired by Friedkin and Johnsen's social influence model [10], we propose the formal model for network influence on an organization's evaluation of candidate collaborative projects. As this model is designed to inform the development of agent-based simulations, it focuses on the perspective of individual agents, i.e., organizations in the network.

3.2.1) *The Formal Model:* Our model studies on how the priority score of a candidate collaborative project assigned by an agent is influenced by the scores of the same project assigned by other agents in the network. The model can be represented with the following equations:

$$S_{i,j}(0) = Eval(P_j, KB_i) \quad (1)$$

$$S_{i,j}(t) = C_i \times T_i \times SN_{i,j}(t-1) + (1 - C_i) \times S_{i,j}(0) \quad (2)$$

where $S_{i,j}(t)$ for $t = 0, 1, 2, \dots$, is the priority score of candidate project j assigned by organization i at time t .

Equation (1) describes how the initial score of project j is determined. The *Eval* function takes two sets of parameters as the input: project j 's characteristics P_j and agent i 's knowledge base KB_i , which stores the project evaluation criteria of agent i . The internal evaluation schemes can be configured by the modeler to cater different scenarios. Our previous work adopted a weighted sum evaluation scheme [35].

Equation (2) is the core of the network influence model and represents how an agent's initial evaluation of a project, i.e. priority score assigned to the project, is iteratively influenced by other agents' evaluations of the same project. The right hand side of the equation consists of two parts.

The first part describes the external influence. T_i is a $1 \times n$ vector that represents influences on agent i from all the n agents in the inter-organizational network, including agent i itself. Elements in T_i are called influence indexes. For example, $T_i[k]$ is the influence index of agent k over agent i . The sum of all influence indexes in T_i is 1, as shown in Equation (3).

$$\sum_{k=1}^n T_i[k] = 1 \quad (3)$$

$SN_{i,j}(t)$ is an $n \times 1$ vector that stores project j 's priority scores assigned by all the n agents. Namely, $SN_{i,j}(t) = [S_{1,j}(t), S_{2,j}(t), \dots, S_{i,j}(t), \dots, S_{n,j}(t)]^T$. Thus the product of T_i and $SN_{i,j}(t-1)$ is a score that reflects agent i 's combined consideration of all other agents' evaluations of the same project j at time $t-1$. The first part is actually very similar to a Markov chain, in which the score at time t depends on the scores at time $t-1$.

The second part is actually agent i 's initial and independent evaluation of project j . The initial evaluation is kept because it is made independently by the agent under no external influence. This will sometimes serve as the basis for possible evaluation deviations during the iterative influence process.

The two parts are connected and balanced with the influence coefficient $C_i (0 \leq C_i \leq 1)$, which denotes how likely agent i 's project evaluation is influenced by others'. In the context of humanitarian coordination, a larger influence coefficient means an organization is more subject to external influence, while organizations with smaller influence coefficient are more independent when evaluating projects and making coalition formation decisions.

As the priority score of a project is often updated, we also take a brief look at the scalability of this model. Given the influence index, the computational complexity for each agent to calculate the priority score for a project is polynomial $O(n)$, where n is the number of agents in the network. The speed of the agent-based simulation based on this model is satisfactory when using a network with over ninety nodes.

3.2.2) The Influence Index: Many may have noticed in Equation (2) that the external influence on an agent's evaluation seems to come from all the other agents in the coordination body and there is no component that explicitly represents influence from an agent's network neighbors. So how is influence from network neighbors reflected in the model? The answer of the question lies in how influence indexes in T_i are defined. In fact, influence indexes can be defined to represent various aspects of inter-organizational networks.

We have talked about the two-phase interaction scheme for humanitarian organizations' coalition formation in Section 3.1. Now we will describe one approach to define influence indexes for the two interaction phases.

In a group meeting, an organization is influenced by all other peers at the meeting as every organization is given the chance to publicly advocate projects it supports. The influence index of organization k over organization i is first calculated as:

$$T'_i[k] = f(\text{size}(k), \text{size}(i)) \times g(\text{dist}(i, k)) \quad (4)$$

where $\text{size}(x)$ is the size of organization x ; $\text{dist}(x, y)$ denotes the geodesic distance between organization x and y in the inter-organizational network.

Equation (4) suggests that influence indexes are based on organizations' sizes and the geodesic distance between organizations in the network. The reason we use organization size is that, inside coordination bodies, larger NGOs often exert more influence on smaller organizations, partly because larger organizations often possess more resources that are critical to the successful implementation of collaborative projects. Hence smaller organizations often need to cooperate with larger organizations in order to get access to important resources they do not possess. Meanwhile, organizations may also be influenced by direct neighbors, as well as non-neighbors, although the influence is often stronger when the two organizations are closer to each other in the inter-organizational network. Such distance-based influence usually decays very fast as the

distance increases.

Therefore, we may use square root of the quotient as f and a Gaussian function as g in Equation (4).

$$f(\text{size}(k), \text{size}(i)) = \sqrt{\frac{\text{size}(k)}{\text{size}(i)}} \quad (5)$$

$$g(\text{dist}(i, k)) = e^{-\frac{\text{dist}(i, k)}{\sigma^2}} \quad (6)$$

where σ is a network-specific parameter that denote the range of effective influence in the network.

Using Equation (4), we can calculate influence indexes of all organizations over organization i and store them in T'_i . Then we will normalize all the indexes in T'_i using the Equation (7), so that Equation (3) holds.

$$T_i[k] = \frac{T'_i[k]}{\sum_{p=1}^n T'_i[p]} \quad (7)$$

Now we move to the phase of private discussions, in which an NGO interact only by its immediate network neighbors. Therefore, an NGO can only get the scores of a project assigned by neighboring NGOs. As a result, if NGO m is not an immediate neighbor of NGO i in the network, $S_{m,j}(t-1) = 0$ in the vector $SN_{i,j}(t-1)$. In fact, scores of projects assigned by non-neighboring NGOs do not matter to NGO i . The definition of influence indexes specifies that, in private discussions, $T_i[m] = 0$ and thus NGO m 's evaluations of projects do not have impacts on NGO i 's evaluations.

The way of defining influence indexes for non-neighbors in the phase of private discussions reflects the network connection of an organization and answers the question at the beginning of this subsection.

We have clarified that there is no influence from non-neighboring organizations in the private discussion. Now we will consider influences from neighboring organizations. When calculating the influence indexes of an organization's neighbors over this organization, the strength of ties is taken into consideration. The index is first calculated using Equation (8):

$$T'_i[k] = f(\text{size}(k), \text{size}(i)) \times h(i, k) \quad (8)$$

This equation shares function f with Equation (4) but uses $h(i, k)$, which indicates the strength of tie between organization i and y , instead of the function g on geodesic distance. Most of the time, the stronger the tie between two organizations is, the more likely an organization is influenced by its network neighbor and consequently the higher the influence index becomes. Similar to the phase of group meetings, after all influenced indexes of an organization's neighbors are calculated, they are then normalized using Equation (7).

It is worth noting that, besides organization size, geodesic distance between organizations and strength of ties, there are other factors that may affect influence in inter-organizational networks, such as trust and reputation. We choose aforementioned functions and variables for this case study mainly based on data availability and quantifiability. Other factors can be incorporated when the data become available. One of the advantages of this model is that it is flexible enough to allow various ways to define inter-agent influence and thus can be

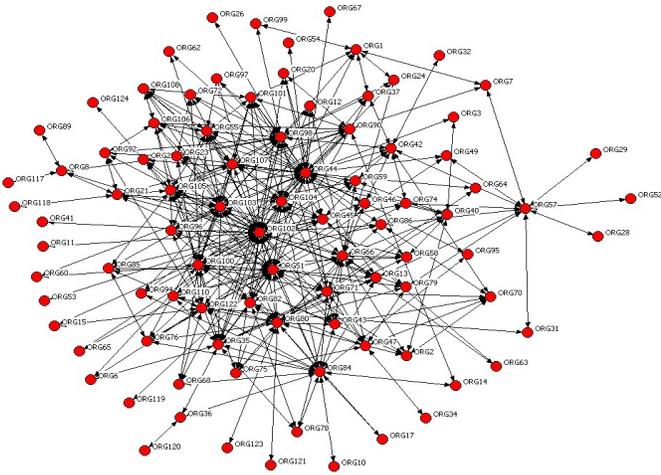


Fig. 1. The inter-organizational advising and information exchange network inside the GlobalSympoNet

adapted for other scenarios that include inter-organizational networks.

3.3. An experiment

We have implemented our formal models as an agent-based simulation using the Repast Symphony simulation toolkit [26]. In this sub-section, we will illustrate the results from a simple experiment of the coalition formation process using our simulation.

The experiment will use data from the coordination body of GlobalSympoNet. Through surveys, we have identified an advice and information exchange network among organizations inside the GlobalSympoNet (See Figure 1). Each node in this network represents a member organization and there are 92 organizations in the network. A tie or connection between two nodes means that the two organizations have previous experience in exchanging information or consulting advice. The network features a topology that is similar to the scale-free network [2]. The diameter of the network is 5, which means between any two organizations in the network, there are at most four other organizations between them. We also categorize organizations into ‘very large’, ‘large’, ‘medium’ and ‘small’ organizations based on the number of staff member in the organization.

However, as explained below, data on the precise decision parameters of organizational representatives is difficult to collect and hence we use simulated data. Basically, 50 candidate projects are generated, representing the collective body of all projects of interest to all member organizations. There ‘projects’ are then in turn randomly assigned to agents’ to-do lists. The maximum size of a to-do list and the number of initial candidate projects on the list are positively correlated to the size of the organization. Then, for each organization, projects on the initial to-do list and projects proposed by others are randomly assigned initial priority scores, representing their importance to the organization.

The decision to use simulated data is both a function of the cost of collecting such data and the phase of the research.

While collecting such data is possible, it is burdensome to the subjects and hence its importance to the simulation must be well-established. Typically, managers in interviews prefer to answer general questions that allow them to reflect on general behaviors. Questions concerning the precise rankings of project priorities are difficult to recall or even specify in the present as they tend to be fluid within a certain range. Hence, only when the research establishes that project lists and priorities are crucial will such data collection activities be pursued.

In the experiment, we will compare the performance of coalition formation in two scenarios: (1) coalition formation with the network influence model and (2) coalition formation without network influence. The first scenario is based on the network influence model that we proposed, while in the second scenario, the evaluation of projects is not subject to influence and does not change once the priority score is assigned. Two simple metrics are used to measure the coalition formation performance under the two scenarios: first, the number of formed coalition within a pre-set time frame; second, the time needed to form a certain number of coalitions.

Specifically, the simulation is initialized with 50 candidate projects and includes 25 rounds of interactions in the group meeting style. The threshold of minimum supporters is $1/3$ of the total number of organizations, i.e., 31 out of 92. For each initialization of to-do lists, we run the simulation for the two scenarios. As for coalition formation metrics, we measure the performance with (1) whether enough coalitions can be formed for more than 30% of the initial 50 projects, and (2) how much time is needed to form coalitions for more than 30% of the initial 50 projects.

Our preliminary results suggest that the scenario with network influence outperforms the scenario without network influence. With network influence, coalitions can be formed for more than 30% of the initial 50 projects within the time frame with a probability of 90%. This probability drops to 42% if there is no network influence. In addition, statistical analysis revealed that the time needed to form those coalitions with network influence is significantly shorter than that without network influence. The result is in accordance with our empirical study of coalition formation in the humanitarian domain. For example, most humanitarian organizations in the coordination body of ReliefTechNet agreed that participating in the coordination body and interacting with peer organizations in this type of inter-organizational network promoted the coalition formation process and facilitate the inter-organizational coordination.

This experiment does not serve as a rigorous validation of this model. However, the results give us a general idea that this implementation of our model is able to reflect some activities that happen in the real-world inter-organizational coordination.

4. CONCLUSION AND FUTURE WORK

In this paper, we propose an approach to model emerging coalitions in the context of inter-organizational network with a case study of humanitarian coordination. The formal model focuses on how an organization’s own evaluation of

candidate collaborative projects is influenced by other organizations' evaluations of those projects in the context of inter-organizational networks.

The model was inspired by the problem we encountered when simulating network influence in humanitarian coordination and has the potential to contribute to other research of coordination in inter-organizational networks. In addition, to our knowledge, this study is the first that tries to model the problem of network influence in agent-based coalition formation. This model is also a general and flexible model, which may be applied to other scenarios that involve the formation of multi-agent coalitions or inter-agent influence in agent networks.

Admittedly, our research is still at an early stage. Future work may include more systematic validation of the model, more data collection and the application of our agent-based simulations to the study of inter-organization coordination issues.

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Kang Zhao is a Ph.D. candidate at the College of Information Sciences and Technology at the Pennsylvania State University. He received his M.S. in Computer Science from Eastern Michigan University and B.E. in Electrical Engineering from Beijing Institute of Technology. He is also a recipient of the Robert W. Graham Endowed Graduate Fellowship. His research interests include complex network analysis, survivable supply-chain networks, computational social and organizational models, and agent-based systems.



Andrea H. Tapia is an Assistant Professor at the College of Information Sciences and Technology at Penn State University. Dr. Tapia is trained as a Sociologist and works in the area of organizational and inter-organizational uses of information and communication technologies. Dr. Tapia's work has focused on public organizations such as first responders, humanitarian and disaster relief agencies, and large public science/laboratories.



John Yen is University Professor and Associate Dean for Research and Education at College of Information Sciences and Technology at the Pennsylvania State University. He received his Ph.D. in Computer Science from University of California, Berkeley, M.S. in Computer Science from Santa Clara University, and B.S. in Electrical Engineering from National Taiwan University. His research interests are intelligent agents, decision supports, and social network analysis, especially within the context of extreme events and social dynamic modeling. He

received the NSF Young Investigator Award in 1992, and is a Fellow of IEEE.



Louis-Marie Ngamassi is a doctoral student in the College of Information Sciences and Technology at Penn State University. He holds a Master's degree in Computer Information Systems from Pace University, New York and B.S. in Economics from University of Yaounde, Cameroon. His research interests include inter-organizational coordination for enhanced Information and Communication Technology (ICT) deployments in the context of humanitarian relief, with an emphasis on the use of ICTs for HIV/AIDS education in Africa. Louis-Marie's

work has appeared in the proceedings of the following conferences: the Biennial Conference of the International Telecommunications Society (ITS); the International Information Systems for Crisis Response and Management (ISCRAM) Conference; the World Congress on Social Simulation (WCSS) and the Research Conference on Communication, Information and Internet Policy (TPRC); and ICT for Africa Conference.



Carleen Maitland is an assistant professor in the College of Information Sciences and Technology at Penn State University. Her research focuses on the international and inter-organizational context of IT deployments and the ways in which national and regional policies influence market development. Her work, including 40 journal articles, book chapters and refereed conference proceedings, has appeared in *The Information Society*, *Telecommunications Policy*, *Information Economics and Policy*, and *Government Information Quarterly*, among others. Also,

her research program has been supported by the European Commission, the U.S. Department of Commerce, the U.S. National Science Foundation, and IBM, among others.