Decisions in Disaster Recovery Operations: A Game Theory Perspective on Actor Cooperation, Communication, and Resource Utilization

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Abstract

Using perspectives from game theory in the problem of cooperative interaction between international and local agencies, we discuss the potential for improvement in humanitarian logistics using cooperative strategies for relief that can be applied globally. On March 11th, 2011, the world turned to Japan and was reminded of the power that can be unleashed at a moments notice (Figure 1). Hit by a 9.0 Earthquake and a 10 meter tsunami, Japan lost thousands and raced to stabilize two nuclear power plants. As agencies around the world race to assist in this new catastrophe, interagency cooperation will be critical as it was following the earthquakes in Haiti and Chili (Coles, Yates, Zhuang, 2011; Kapucu, 2006). The approach and sensitivity of these organizations to the culture and to one another could significantly improve the efficacy of the relief operations and significant impact the long-term recovery of the region economically and socially (Hausken, 2002; Rowan, 1994).

Figure 1: Yamada, a Japanese town in Iwate Prefecture, is seen here after being rocked by an earthquake, swamped by a tsunami, and ravaged by fire. The 9.0 earthquake and following events have shaken what is traditionally considered one of the most prepared nations in the world for earthquakes and tsunamis. (Shimbun, 2011)

Project Objective

Since the time necessary to sufficiently understand an unfamiliar situation may not be available to the in an emergency environment, we here discuss a methodology for utilizing interactions between local and external actors to increase efficiency in the final stage of emergency management: the recovery phase. By analyzing the dynamics of relationships that may occur in disaster recovery through the lens of game theory, we provide a new perspective on optimizing the efficacy of disaster relief operations (Hausken, 2002; Marschak & Radner, 1972). In this project we provide a framework describing a two-player game involving local and external/entering actors where their objective is to maximize the perceived impact of their effort (Coles, Zhuang 2011).

The Two-Player Game

- Game of Imperfect Information
  1. Actors choose whether or not to work together.
  2. Actors chose level of relational effort
- Partnership Possibilities
  1. A local (I) and external (E) actor
  2. Two local (I) actors
  3. Two external (E) actors
- Types of Actors
  1. Business
  2. Government Agency
  3. Individual
  4. Military
  5. Nonprofit Organization

	External Actor (P)	External Actor (NP)
Internal Actor (P)	$U_E(x_I, x_E)$; $U_I(x_I, x_E)$	u_E ; $U_I(x_I, x_E)$
Internal Actor (NP)	$U_E(x_I, x_E)$; u_I	u_E ; u_I

	External Actor 1 (P)	External Actor 1 (NP)
External Actor 2 (P)	$U_{E1}(x_{E1}, x_{E2})$; $U_{E2}(x_{E2}, x_{E1})$	u_{E1} ; $U_{E2}(x_{E2}, x_{E1})$
External Actor 2 (NP)	$U_{E1}(x_{E1}, x_{E2})$; u_{E2}	u_{E1} ; u_{E2}

Utility Functions

Utility Structure

x = Effort level; As perceived by actor
Basic Structure: Perceived Impact
$U_E(x_I, x_E) = B_E(x_I, x_E) + C_E(x_I, x_E)$

Benefit: $B_E(x_I, x_E)$
- Partnership benefit
- Individual actor benefit
- Coopetition Effect

Cost: $C_E(x_I, x_E)$
- Actor Cost
- Cultural barrier cost

Constants

α = Partnership efficiency coefficient
a = Primary agency partnership factor
β = Primary agency efficiency coefficient
b = Secondary agency partnership factor
θ = Primary agency efficiency factor
γ = Cultural barrier and competition coefficient
ε = Agency cost coefficient
δ = Damping constant for partnership utility

External-Internal Utility

External: $U_E(x_I, x_E) = \left(\alpha_E x_E^a x_I^b + \beta_E x_E^\theta\right)\left(1 - e^{-\frac{\delta_E x_I}{x_E}}\right) - \gamma_E(x_E - x_I)^+ - \varepsilon_E x_E$

Internal: $U_I(x_I, x_E) = \left(\alpha_I x_E^b x_I^a + \beta_I x_I^\theta - \gamma_I(x_E - x_I)^2\right)\left(1 - e^{-\frac{\delta_I}{x_I}}\right) - \varepsilon_I x_I$

External-External Utility

External (1): $U_{E1}(x_{E1}, x_{E2}) = \left(\alpha_{E1} x_{E1}^a x_{E2}^b + \gamma_{E1}(x_{E1} - x_{E2})^2\right)\left(1 - e^{-\frac{\delta_{E1} * x_{E1}}{x_{E2} + x_{E1}}}\right) - \varepsilon_{E1} x_{E1}$

External (2): Same with reversed variables

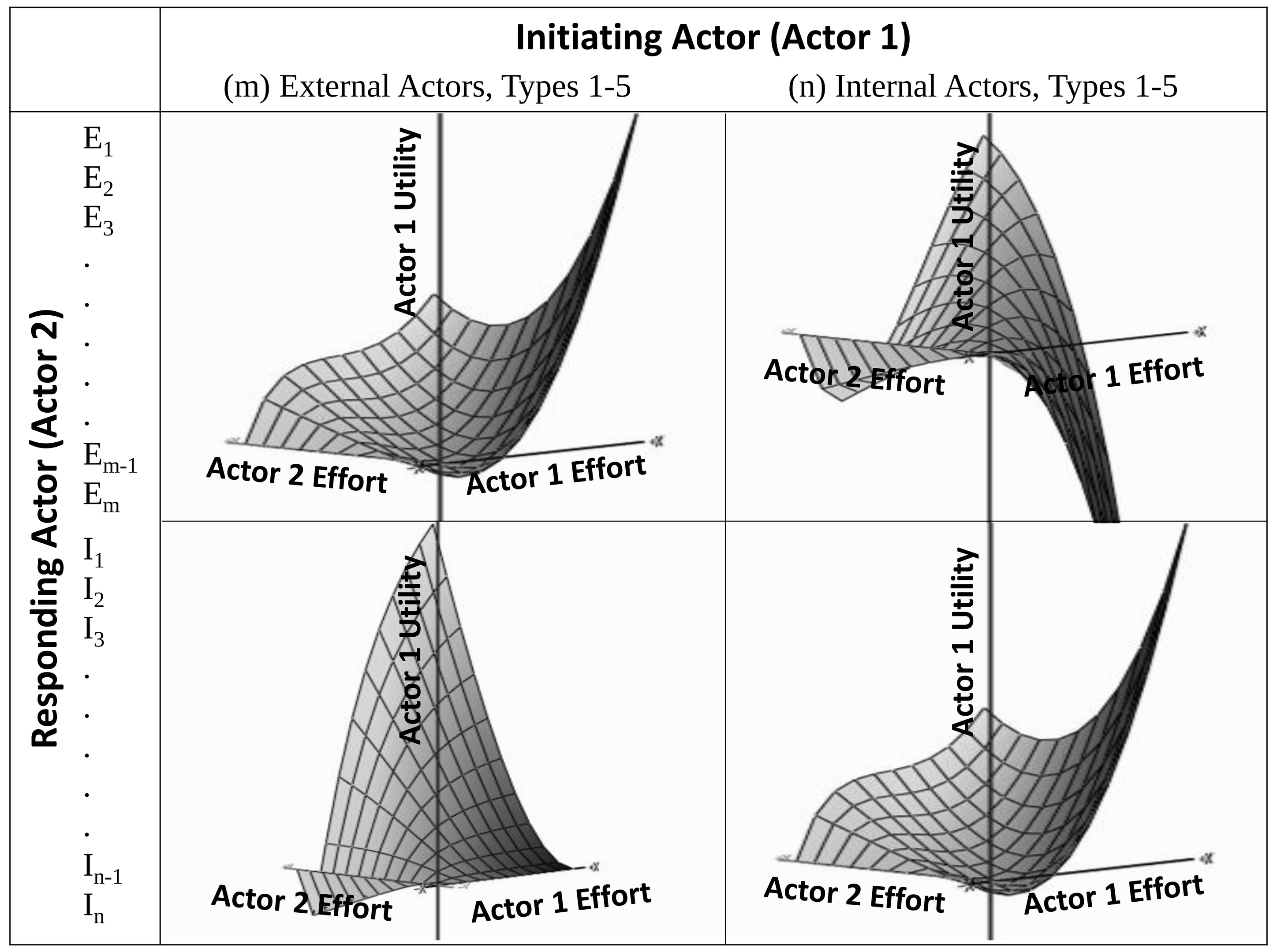
Internal-Internal Utility

Internal (1): $U_{I1}(x_{I1}, x_{I2}) = \left(\alpha_{I1} x_{I1}^a x_{I2}^b + \gamma_{I1}(x_{I1} - x_{I2})^2\right)\left(1 - e^{-\frac{\delta_{I1} * x_{I1}}{x_{I2} + x_{I1}}}\right) - \varepsilon_{I1} x_{I1}$

Internal (2): Same with reversed variables

The Large-Scale Partnership Game

Large-scale disaster such as Japan, Haiti, and Chili.
- Large number of actors involved
- Actors can choose whether or not to partner, and with whom to partner
- Different actor types have different coefficients for partnership efficiency



Partnership Development Following the 2010 Haitian Earthquake

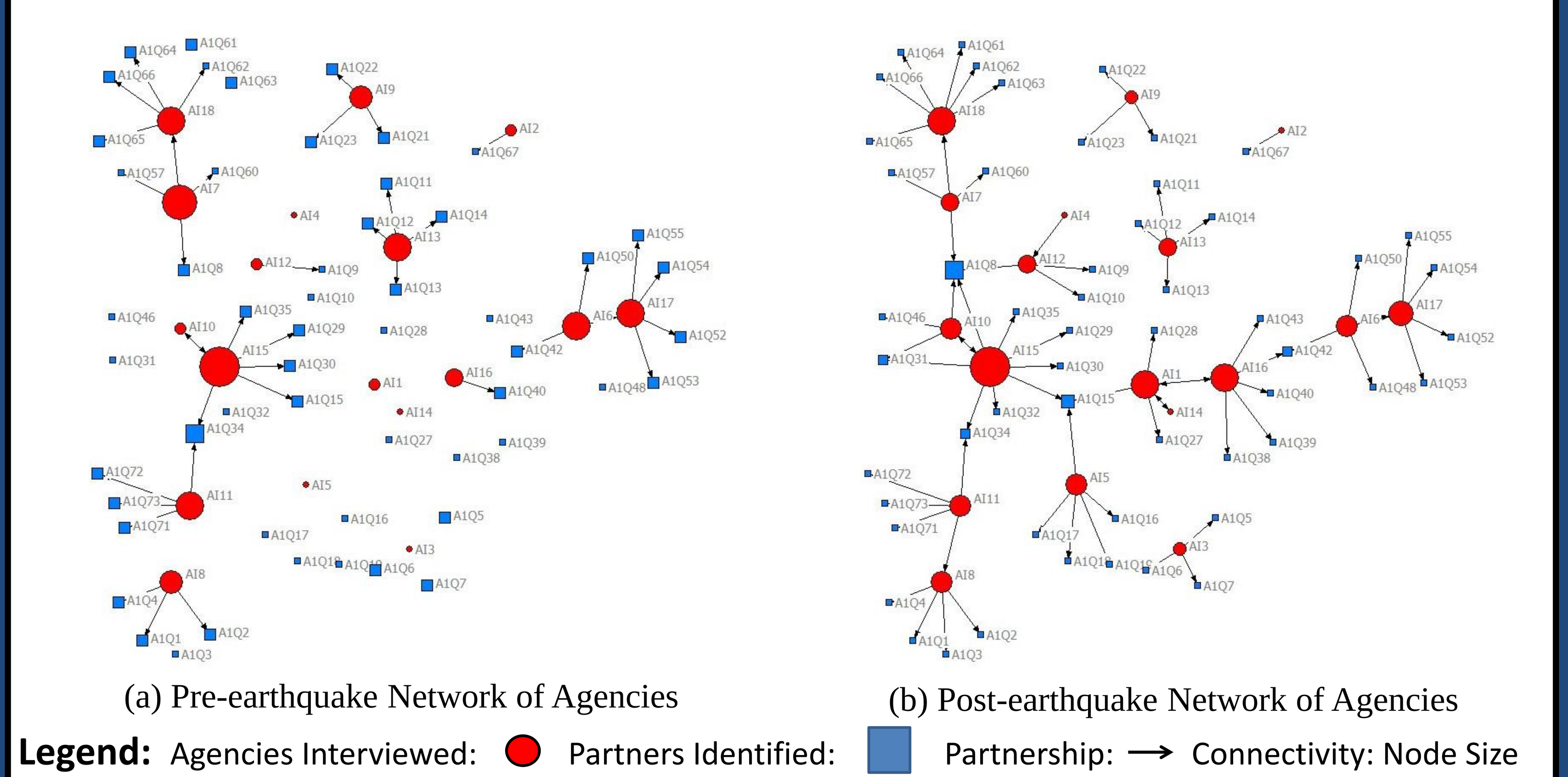


Figure 2: Networks (a) and (b) were developed from interviews conducted under NSF RAPID Grant #1034730. Using the results we identified the major actor types and utility functions.

Conclusion and Future Work

By examining the partnership problem using game theory, we were able to develop a framework for emergency managers to use when responding to a disaster and forming new relationships. Using partnership dynamics identified in the literature, and data from previous research, we have developed simple, quantifiable objective functions dependent on the values in a comprehensive table of actor interactions. We hope to continue development of this framework and provide actors entering unfamiliar environments with tools to rapidly assess the utility of partnerships and optimize resource allocation.

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