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John Coles, *University at Buffalo*
Jun Zhuang, *University at Buffalo*

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Decisions in Disaster Recovery Operations: A Game Theoretic Perspective on Organization Cooperation

John Coles and Jun Zhuang

Abstract

Throughout history, disasters have had a defining impact on individuals, governments, and society as a whole. The terrorist attacks on September 11th, 2001 and several catastrophic hurricanes in the gulf region have brought disaster response and emergency management to a new level of visibility and importance in the United States. The increased media coverage of international disasters, such as the Indian Ocean Tsunami in 2004 and the Earthquake in Haiti in 2010, have resulted in international disaster response and recovery efforts becoming a larger part of foreign policy for developed countries. The changing scene of disaster response and recovery has also resulted in a rapid increase in the number of private organizations emerging to assist in the wake of such catastrophes. There are significant cross-cultural dynamics and interoperability issues that become apparent when new actors (governments, businesses, organizations, etc.) enter an unfamiliar disaster environment which could reduce the operational efficacy of both local and foreign actors. In this project we propose an approach to support and guide decision makers in emergency environments on how to select and develop relationships to improve resource utilization and project outcomes in the wake of a disaster. Using game theory, we provide an initial approach for the development of a decision support framework for emergency managers entering a disaster environment.

KEYWORDS: game theory, organization cooperation, partnership, disaster relief

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1. Introduction

The Indian Ocean tsunami which struck on December 26th, 2004 killed over 230,000 people, destroying housing and critical infrastructure everywhere it landed. As a result, one of the largest international relief efforts in modern history was mounted to save life and property, and to stabilize the devastated region. Among the successes and failures of the response, an overwhelming need for cultural understanding and sensitivity became apparent to make the response and recovery efforts sustainable. Although sensitivity to cultural issues is challenging in the initial response phase, identifying sustainable methods of aid distribution throughout the recovery phase is critical to local acceptance while minimizing the chance of long-term dependence on outside assistance. A lack of sensitivity to these critical issues could reduce the positive long-lasting changes or recovery in the region due to where aid delivery does not address economic and social issues in a culturally acceptable manner. With the recent disasters in Haiti and Chile in January and February 2010 respectively, the need for a more holistic approach to actors' cooperation has become increasingly clear. Using perspectives from game theory in the problem of cooperative interactions between international and local actors, we discuss the potential for improvement in disaster management and cooperative strategies across the developing world.

Large-scale emergencies, also called disasters, are a global phenomenon. From Indonesia to Haiti, disasters have killed hundreds of thousands of people, destroying local infrastructure and leaving millions of people homeless. In the United States, Hurricanes Katrina and Ike demonstrated the remaining vulnerability of developed countries to natural disasters, despite the large number of actors dedicated to responding to these scenarios at the local, state, and federal levels. Differences in culture and context make it essential for organizations, government, and individuals responding to a disaster to be prepared to work effectively in an unfamiliar environment even within a common national border. Disaster relief and emergency management have played an increasingly significant role in foreign policy for the United States and other developed countries.

Destruction and loss following a disaster tends to attract a variety of organizations offering resources and services to support the redevelopment of the stricken area. These services range from medical care to business guidance. Due to the unique nature of each disaster, and cultural differences between different impacted areas, it is critical that any actor entering such a situation approach it with a clear objective, maintaining an open mind as to how it might be accomplished. This paper provides new insight into the dynamics that may occur when actors enter a new environment, and well-established local actors interact and develop working relationships. By analyzing the problem of actor

partnerships in disaster recovery, this paper provides a new game theory perspective on how to model these relationships, and how emergency managers could better utilize their resources during the recovery effort.

1.1 Problem Definition

In the complex and dynamic environment that follows after a major disaster, it is essential that organizations, agencies, and individuals, collectively called “actors” in this paper, be able to manage and utilize their resources to effectively respond. The choice of when, where, how, and with whom these resources should be deployed is a complex problem in emergency management. The actors involved in emergency management would choose how to utilize the available resources to maximize the impact in disaster environments. This problem of optimal resource allocation becomes more complicated when the decision makers act in environments that are unfamiliar to them. The lack of familiarity with an environment could decrease the efficiency of decision makers due to the increased complexity and the potential addition of unidentified factors in the new environment. By providing a decision support framework for emergency managers in the process of developing partnerships, and framing it as a game theory problem, this paper explores a new methodology to maximize the efficiency of actors involved in disaster recovery.

1.2 Objective and Structure

Since the time necessary to sufficiently understand an unfamiliar situation may not be available to the actors in an emergency environment, we here discuss a methodology for utilizing interactions between 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 improving the efficiency of disaster relief operations.

The remaining of the paper is organized as follows. Section 2 introduces game theory terminology and how it could be applied to decision-making in the context of disaster recovery operations. Section 3 explores emergency management and delves into the nuances of disaster recovery and actor-actor partnerships. Section 4 discusses the new framework developed to support emergency managers by integrating game theory and disaster recovery. Section 5 provides a discussion of the limitations of this approach and real world examples to which this research could be applied. Section 6 concludes our paper with an overview of what our paper contributes to the body of knowledge and a discussion of some future research topics in the area.

2. Game Theory

In the development of a holistic approach to disaster recovery operations and actor relationships, we first review some terminology of game theory used in this paper as follows:

- **Actor (Player):** This term is broadly used to mean an organization, agency, individual, government, or business that is involved in a game with other actors.
- **Benefactor:** An actor that provides resources to another actor.
- **Game:** A framework for interaction between actors.
- **Entering Actor:** An organization, agency, individual, government, military, or business that did not normally operate in the affected region prior to the disaster. This includes actors based internationally as well as actors that operate in the same country but are not familiar with the specific nuances of the local area affected by a disaster.
- **Local Actor:** An organization, agency, individual, government, military, or business that operated in the affected region prior to a disaster.
- **(Nash) Equilibrium:** The balance point in a game where no actor could benefit by changing his/her strategy while the other actors keep their strategies unchanged.
- **Payoff:** The benefit(s) received by each actor at the conclusion of a game.
- **Objective:** The maximization or minimization of certain goals for each actor in a game.
- **Outcome:** The result of a game after it is played, including the payoffs for each actor.
- **Partnership:** A relationship between two actors where goods or information is exchanged and all involved are perceived as equals without one being subject to another. Accountability is mutually given and received.
- **Game with Perfect Information:** A game where each actor knows the options that the other actors are faced with, and if it's a sequential game, the choices that previous actors in the game have made.
- **Sequential Game:** A game where the actors involved make decisions in sequence and some information regarding the decision made by the first actor may be available to the second.
- **Simultaneous Game:** A game where actors make their decisions at the same time. As a direct result, neither party is able to know what the other has decided when making their decision.

Using the terminology defined above, we discuss how game theory could be applied to decision-making in the context of disaster recovery operations. Game theory studies the interaction of multiple actors and the outcomes that occur as a result (Camerer, 2003). These interactions can be broken down into specific “games” where a finite set of actors interact for some period of time, resulting in a payoff for each actor involved. Using mathematics and probability to model these interactions, game theory can help to predict the outcomes of future interaction between actors, and even provide decision support for future circumstances (Rasmusen, 2007). Game theory has been applied to a variety of different circumstances and environments providing, among others, valuable insight on counter-terrorism operations (Hong & Apostolakis, 1993; Hausken, 2002; Zhuang & Bier, 2007).

Games can take many forms where two actors may move sequentially, with actors “playing” one after another, or simultaneously, where both actors choose a strategy prior to approaching negotiations (Shor, 2006). Another element that impacts the games in coalition formation is when varying amounts of information is available to the actors, and what degree the information available can be trusted (Kapucu N. , 2005).

By increasing local participation in the recovery process, efforts to restore what was lost would be motivated by local individuals rather than by external capital and personnel, which leave when the recovery phase for a given organization is over (Tolentino, 2007). This is greatly desirable for both the local economy and society in the long run, as it could improve the livelihood of pro-active local individuals, and even may initiate a locally driven movement to mitigate future disasters (Mainville, 2003). The development of relationships within the disaster community is also critical to an effective and efficient recovery (Kapucu, 2008; Hall, 2008). Although resources such as food, machinery, and clothing are necessities in response and recovery efforts, they cannot be effectively utilized without properly trained and located personnel. Thus, the formation of partnerships allows for the maximization of the intersection of the necessary materials and conditions needed to effectively meet local needs.

Given the large number of criteria involved in disaster recovery operations, the problem of formulation related to interactions between actors could be complicated; however, decision and risk analysis methods could help to quantify these comparisons (Cox, 2009). By focusing on the dynamics of actor-actor interactions individually rather than collectively, the system dynamics as a whole could be modeled using game trees (Hong & Apostolakis, 1993; Myerson, 1997). Game theory has proven useful in the analysis of multiple complex dynamics within disaster management processes (Shermemetov, et al., 2004). Using game theory, people can examine probabilistic sub-problems and identify

the total system output for the complex recovery environment (Hausken, 2002; Marschak & Radner, 1972).

The issue of actor-actor coalition formation is complex due to the unique nature of each separate relationship. While partnership formation is not a simple problem to begin with, dynamics during emergency response and recovery operations add some additional elements of complexity, which makes the proof of a general coalition theorem for this particular problem elusive. There are four primary factors to be addressed in order to ensure that the problem of coalition formation is effectively approached by all parties during an operation: (a) the different types of actors that could be involved; (b) the challenge of cross-cultural coalitions; (c) the differences in overarching scenario methodology directing operations; and (d) the different dynamics of a partnership that could fundamentally alter the progression of the game. While the presence of each of these particular dynamics may be easy to identify in practice, the understanding and adaptation necessary to appropriately respond to these unique dynamics may prove challenging in practice.

3. Emergency Management

Emergency management is the process of preparing for and responding to any emergency or disaster. In this paper, we use the definition of “disaster” provided by the National Governors Association of the United States that defines a disaster as any “event that demands substantial crisis response requiring the use of government powers and resources beyond the scope of one line agency or service” (Haddow, Bullock, & Damon, 2008). The four stages of emergency management are mitigation, preparedness, response, and recovery (Comfort, 1990). Mitigation and preparedness occur prior to the disaster, and serve to minimize the impact of a disaster and plan the response and recovery phase ahead of time. Response and recovery are the short and long-term approach, respectively, where actors assist an affected area following a disaster. Due to time constraints and the significant effect of decisions made regarding lives and property, the development of relationships between actors is a complex problem during all four stages of emergency management. For our discussion of relationships in disasters, we focus on actors entering a disaster scenario, defined here as “entering actors,” and those actors which had an established operation prior to the disaster, the “local actors.”

Advanced planning assists in the achievement of greater efficiency during disasters, primarily because it decreases the number of unknowns and allows for a focused and cooperative effort by multiple actors. Much of the research on partnerships during emergencies points to greater efficiency being achieved through previously established relationships (Telford & Cosgrave, 2007; Kapucu,

2008). To sustain a high level of preparedness, external actors would ideally sustain partnerships with local actors in as many disaster-prone areas as possible, allowing them to work solely through previously established relationships.

While the type of actors involved in disaster recovery operations are situation dependent, we here refer to all representatives of these actors as emergency managers for the sake of consistency. Emergency managers are defined here as the individual(s) representing an actor in an emergency situation. These individuals are empowered to make decisions in real-time, including decisions about resource allocation and partnership formation. Since both local and external actors have limited resources, and a vast number of areas could require such partnerships, it is critical that methods be developed to generate a high level of efficiency in response efforts through local and external partnerships formed in a short time frame (Rowan, 1994; Kapucu, 2006). In order to perform this task effectively, it is critical that emergency managers be given the proper tools and information to make the best decisions for their organization.

3.1 Emergency Management and Game Theory

The application of game theory in dynamic situations should be performed with caution. The fundamentally indeterminate elements that compose a disaster or emergency make it helpful for any decision framework applied to be inherently flexible. The maximization of organizational cooperation is often more realistic when applied during the recovery phase of a disaster. It is difficult to provide emergency managers with information accurate enough to create an optimal, long-term strategy that could be implemented at the outset of an event in the immediate aftermath of a disaster (Hausken, 2002).

One key driver of cooperation and partnership between actors in disaster response and recovery operations is field interaction between first responders (Wilson & Musick, 1997; Smith & Dowell, 2000). When actors are simultaneous working in the same geographic location, the probability of them cooperating is much higher, due to natural convenience and the potential gain of a partnership. Any holistic framework modeling the development of partnerships between actors would incorporate the subjective assessments of field personnel. Such quick judgments made by the field personnel are critical to operational success and actor efficiency in the field. These subjective assessments of other actors provide a referent for emergency managers when developing partnerships.

3.2 Actor-Actor Partnerships and Disaster Recovery Operations

The maximization of organizational cooperation is often unrealistic for large-scale scenarios during the response phase. Due to the necessity of rapid response, and

the tendency of individual actors maximize individual rather than collective outcomes, uncoordinated work by multiple actors may not lead to the best collective solution (Hausken, 2002). Hence, a key driver of cooperation is field interaction between first responders on the ground in the regions to which they are actively responding (Wilson & Musick, 1997; Smith & Dowell, 2000). The best achievable minimization of loss in life and property in these areas is often the direct result of coalitions formed out of necessity, the basic human drive to preserve life, and previously formed procedures (Kapucu, N., 2006). Since there may be little time for stable relationships to form during this time, the sharing of resources during the response phase is facilitated through need-based cooperation (Bergantinos, et al., 2007; Kapucu, 2008). Though there are a variety of rule-based approaches to risk communication, it is critical that general heuristics are developed to aid sustainable development of partnerships formed under sub-optimal conditions (Rowan, 1994).

As demonstrated by large-scale disasters such as the Indian Ocean tsunami in 2004, and the recent Haiti earthquake in January 2010, the significance of effective cross-cultural partnerships has been clear. Without such relationships, there may be less effective use of resources due to miscommunication, misunderstood objectives, and a lack of a common operating perspective. The challenges of cross-cultural cooperation may occur even within a community, and responding actors, even within their jurisdictions should always be aware of the potential need to address local customs or boundaries.

Some of the challenges that may arise during an attempt by multiple actors to coordinate their activities are differences in relief methods, goals, and terminology. These challenges make the common operating perspective more difficult to create, and cooperative behavior more challenging to model, since the resulting combination of these three possible differences is difficult to predict. Actors attempting to partner across cultural boundaries would need to be aware of what objectives could be subject to change/interpretation and which are non-negotiable in order to effectively determine what partnerships would be productive.

4. Application of Game Theory in Disaster Recovery

In the case of multi-actor cooperation within a disaster, one of the key challenges faced by responders in disaster recovery is the development of a common operating perspective. Communication is essential for the development of a stable operating perspective between different actors. To that end, identifying the similarities in organizational objectives would provide a useful starting point. When developing a model for actor-actor interactions, it is critical that the techniques to determine the estimated payoffs values, and different outcomes, are

standardized across costs, benefits, and objectives. Due to the differences in how actors measure success in disaster recovery operations, it could be challenging to create a common operating perspective to measure efficiency and productivity from an independent perspective. Once a common operating perspective is established, actors could coordinate their decision making in order to get to the optimal outcome to their collective decision. This process allows the different actors to decide if their common interests are close enough to warrant the creation of a team or partnership (Marschak & Radner, 1972). If additional perspective is added to both actors' operating picture, then there is potential for a shift in perceived payoffs, which could improve the combined outcome for both actors, which could result in a more stable long-term partnership.

4.1 Theoretical Basis for Application

In our problem formulation, we propose to break the actors involved in disaster relief into two specific subsets: local actors and external actors. As defined earlier, the local actors are those that were present prior to a disaster, while external actors are those that entered the scene after a disaster. By dividing the actors into these two subsets, we then discuss some of the perceived characteristics of these different groups.

Based on the proposed separation of actors, we then attempt to identify whether there are fundamental differences in their objectives. For our analysis of the operations of entering actors, we argue that the primary objective of partnerships with local actors is to maximize operational efficiency and perceived impact. This assertion is based on the definition of an "external actor," where we assume that the actor is new to the disaster zone and is coming in with some constrained set of resources of skills with the goal to apply them optimally. Partnership with local actors is one avenue for the entering agency to expend resources to achieve the greatest perceived outcome. In order to provide a more general framework, we intentionally avoid defining exactly what the desired and perceived outcomes an actor might be seeking.

The other set of actors active following a disaster are the local actors. These are the actors that were active in the disaster zone prior to the causal event/disaster. The objective that we associate with local actors, in their development of partnerships with entering actors, is the maximization of resources acquired that could be applied to the relief goals of the local actors. This assumption is based on interviews conducted by the researchers in Haiti following the January 12th, 2010 earthquake. It was found that over 50% of local organizations interviewed wanted free or subsidized products out of the partnerships with an entering actor.

An additional aspect of differences in direction methodology that needs to be considered is the differences in cultural norms and objectives, which may be integral to the central response methodology. Although some of these issues come out in cross-cultural partnership formation, it is also important to mention the effect that the culture of the directing methodology may have even on partnerships between actors with similar cultures. When considering partnership formation, it is critical to ensure that such partnerships increase actors' abilities to achieve their objectives. Furthermore, when these objectives and methods are dynamic due to an unfamiliar direction methodology, it is critical that more caution is exercised in partnership formation by both entering and local actors.

4.2 Historical Real-World Examples

Here we explore three case studies that provide anecdotes for why this model could be useful in disaster recovery environments.

4.2.1 Hurricane Mitch

In the case of Hurricane Mitch in 1998, bean production in Honduras suffered massively with a national cumulative loss of 35% of the bean production for that year (Mainville, 2003). Mainville compares three different markets, and the intervention methods used to highlight the importance of working with localized channels while diverting resources from the profit-based commercial market. Some of the systems that normally rely upon commercial channels for the bean seed were challenged, but did not suffer extensively since pricing was frozen across the country in order to assist the relief effort. Due to this partnership between the local and international actors, the amount of money spent on diverting relief supplies to the hardest hit areas was kept significantly lower by not having to pay for the natural increase in price as a direct result of loss in demand. By partnering with the local community to meet the needs of those within it, the external actors had a better opportunity to maintain an external identity rather than being viewed as a permanent benefactor (Donovan, et al., 2006).

As noted by Donovan, the timing and method of food aid injection is critical to encourage development within a region that is recovering from a shock. The distribution process could be performed by local entities, which have previously served a similar purpose rather than by new, theoretically temporary, mechanisms being put in place. By partnering with local actors in the relief effort, external actors adhering to previously existing distribution mechanisms and techniques in the recovery process would be better able to exit a scenario without the population feeling abandoned. Since the local actor would still be in place

after the external actor leaves, the transition challenge could be reduced through a minimization of the entitlement phenomenon. By examining this problem from a game theory perspective, it was necessary for the external actor to alter their utility function to integrate both short and long-term goals to succeed in assisting their partner without being viewed as a benefactor.

4.2.2 Indian Ocean Tsunami

After the Indian Ocean tsunami in 2004, an international coalition was created to evaluate the response to the disaster, and the results were summarized in the Tsunami Evaluation Coalition's (TEC) Synthesis Report, authored by Cosgrave and Telford in 2006. The report noted that some of the most effective work was done through the partnership of international NGOs (Non-Governmental Organization) with local response efforts. A key conclusion from this report was that such relationships are vital to effective and sustainable response operations. This result was confirmed through later work done by Telford and Comfort (2007). The TEC also noted that, "The engagement of international actors with local capacities was most effective and efficient when it was built on sustained prior partnerships with the local actors." However, it was also found that several international actors satisfied their staffing requirements by poaching from local actors. Though it is not known how widespread this practice was, it is clear that there was a significant negative effect on the local actors that had lost the personnel. From the perspective of the developed framework, it is clear that actors that chose to partner with local actors were more effective in an absolute sense than those that poached.

The massive influx of aid to the region following the Indian Ocean tsunami of 2004 not only met the needs of the victims in the region, but also overwhelmed the area. One case of poor resource management is discussed in Telford and Cosgrave's work (2006). Following the devastation wrought on the Indonesian region of Aceh, especially in coastal businesses, thousands of fishing boats were imported by aid organizations. However, when the boats were given to local fishermen, they proved to be unsuitable to the water conditions because they were made of the wrong kind of wood (Telford & Cosgrave, 2006). Massive waste could have been avoided in such situations by partnering with the local people and understanding the needs of the area (Smith & Dowell, 2000). Had the external actors accounted for their lack of local familiarity, they could have avoided being perceived as a benefactor by partnering with local actors. This partnership could have allowed them to change their utility function to incorporate a success of meeting the local conditions as a part of their success metrics.

4.2.3 Haitian Earthquake

The situation that unfolded following the earthquake in Haiti provides a unique look into the potential devastation that could be wrought on a country's central government. With the United States military and other American aid actors serving in positions normally occupied by a country's government, this potential phenomenon is one which actors entering into such complex international scenarios need to be aware of since avenues of official communication and overarching objectives may be unstable or more challenging to identify.

Disaster management operations have advanced greatly in recent years in the developed world, with improved equipment and communication as well as standardized organizational structures. In the developing world, the advantages of these new advances have yet to be realized, even when international actors respond to a local disaster as highlighted by the recent disaster in Haiti. The differences in individual and cultural objectives are significant enough between regions that implementing standard practices of a developed nation in developing regions often creates dependencies and becomes ineffective in assisting the local population in sustainable ways. To improve the outcome and perspectives of work, it is important to include a cultural aspect to a game theory utility function. This may allow the actors to recognize when they may accomplish their objectives in name and action by adapting to local cultural norms.

By partnering with local actors during the recovery phase of a disaster, external actors have the opportunity to assist the population in sustainable and culturally appropriate ways. Through the process of adapting organizational objectives to a region's cultural and social norms, aid dispersed may have the potential to reach further, even when measured by the organization's original objectives. The exception to this would be cases in which the organizational objectives violate local norms, and the assistance rendered by the external actors would likely do more harm than good in the long run.

5. Discussion

The perspective presented in this paper provides insight into the problem of actor partnerships in order to support decision makers in disaster recovery environments. We here further develop the suggested framework by addressing some limitations of a game theory based framework for disaster recovery operations, and then applying the proposed framework to real-life examples of disaster recovery operations.

5.1 Approach Limitations

While the framework suggested may help solve some of the problems encountered by emergency managers, it is not sufficiently developed to provide a holistic assessment tool for emergency managers. While we describe some of the problems facing emergency managers during the recovery phase of the disaster, it is clear that this approach is not all-encompassing. The use of game theory in our approach to the problem of actor partnership development and stabilization during emergencies provides additional insight to the deterministic aspects of the relationships developed, but may not completely account for all possible emergent phenomena.

5.2 Future Work

In future iterations of this framework, it would be interesting to include an analysis of relationships between external actors and funding sources. An analysis of the local-external actor relationship could then be analyzed with greater depth by integrating the additional needs of the external agencies (e.g., demonstration of effective recovery operations in order to obtain additional/future funding). Though this piece is challenging to quantify, it has been identified as a significant factor in relationships that remain stable over a long recovery period. This factor could be incorporated into the external actors' efficiency calculations, providing insight into how partnerships are tailored to improve public image and develop, augment, and sustain resource flows.

As this approach becomes more accessible to emergency managers and first responders, the integration of actors' perceptions of each other prior to the formation of a relationship should become a larger part of the model. By including these subjective observations in a quantitative framework, we can better account for the subjective nature of such relationships, while simultaneously utilizing the value that such observations have when received from well-trained personnel. Though the relationships that form during emergency response and disaster relief dynamic and complex, it is essential that work continues to overcome the obstacles and provide managers with tools to make organization-wide and tactical decisions.

6. Conclusion and Future Work

The development of a holistic framework for actors interacting across cultural boundaries has the potential to greatly increase the efficiency of those responding to a disaster. The development and provision of support tools could provide guidance to emergency managers during the recovery phase of a disaster, making

operations more efficient, productive, and sustainable. Further improvement of this framework, and development of parallel utility functions from disaster data, could provide support mechanisms for emergency managers when considering how best to approach potential partners in future scenarios. In future research, it would be helpful to use probabilistic components in the model in order to incorporate the variety of different actors that participate in disaster recovery.

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