Game Theory Applications in Humanitarian Operations: A Review

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1 Introduction

Scholarly literature well documents the complexities faced by humanitarian logisticians (Balcik *et al.*, 2008, Jiuh-Biing, 2007, Kovács and Spens, 2007, Nagurney and Yu, 2011, Overstreet *et al.*, 2011). Like their commercial sector counterparts, humanitarian supply chains are designed to deliver the correct quantity of goods to the right place at the right time. However, humanitarian supply chains encounter additional challenges, including damaged transportation and communication infrastructure in unstable or even hostile environments (Balcik *et al.*, 2010). This makes obtaining accurate information difficult (Maiers *et al.*, 2005) in circumstances that require quick, decisive action. The resulting uncertainties and propensity for disruption greatly complicate decision making processes. Another obstacle to successful disaster response is the decentralized nature of humanitarian operations. Multiple agencies are engaged in humanitarian response, and each makes decisions about supply chain functions according to its own objectives and available information. Urgency, in addition to incompatible languages, information technology tools, and data standards, inhibits agency collaboration (Maiers *et al.*, 2005). Decentralization is a great challenge in disaster response because independent decisions of non-governmental organizations (NGOs), governments and military entities, and beneficiaries impact relief outcomes for the whole system.

Game theory is a powerful tool for modeling the interactions of independent decision makers, including the stakeholders in humanitarian supply chain systems. A branch of mathematics long used in economics and political science to model human interaction, game theory has also been applied to commercial supply chains to maximize value (Ketchen and Hult, 2007), optimize cooperative efforts (Cachon and Zipkin, 1999), and form marketing strategy (Huang and Li, 2001), all of which are also relevant in humanitarian operations. Game theory models decentralized decision makers as players in a game, each of whom makes decisions according to the game's structure and his own goal. The game's outcome represents the results of interactions between decision makers.

Although applications of game theory to commercial supply chain settings are increasing, its use as a tool to analyze and improve humanitarian supply chains is limited to date. This paper surveys existing literature that illustrates ways in which game theory has been and can be utilized within humanitarian relief operations. As this is an emerging field, we draw broadly from literature in operations research, humanitarian logistics, and political and management sciences. The contributions of this paper are two-fold. We first document the facets of humanitarian operations to which game theory has been applied in a comprehensive summary of relevant literature. Secondly, we identify opportunities for future research in the field. We begin the paper with a brief overview of game theory. Sections 3 and 4 present literature on competition and cooperation, respectively, between NGOs. Section 5 discusses game theoretic models that integrate the decisions of government authorities, while Section 6 describes models of beneficiary decision making. In Section 7, we synthesize our findings and suggest avenues for future research.

2 Game Theory Primer

A game theory model, or simply a 'game', consists of several elements. The first is a set of players, each with a set of strategies from which to choose. Each player also maintains a goal, often expressed mathematically as a utility function to optimize. The combination of strategies chosen by all players determines the outcome of the game and the consequences, or payoff, to each player according to his utility function. In a game theory model of humanitarian operations, players represent stakeholders or decision makers, such as NGOs, government agencies, donors, or beneficiaries. Examples of payoffs in this context include minimized costs, efficient delivery of services, accurate demand estimation, number of beneficiaries reached, funds raised, and the level of public awareness created.

Game theory models are classified along several dimensions. In *simultaneous* (or *static*) games, all players make a decision at the same time, while *extensive* (also *sequential* or *dynamic*) games involve a sequence of decisions where some players observe the actions of others before deciding upon their own. A game is *symmetric* if the same set of strategies is available to each player and each player's payoff depends only on the combination of strategies played, not on the identities of those playing them. Otherwise, a game is *asymmetric*. Games of *perfect information* are those in which each player knows the actions available to other players, their payoff functions, and any decisions that have already been made. If players are not perfectly informed about these characteristics, the game is one of *imperfect information*. Games may be classified according to payoffs, where *zero-sum* games are those in which anything gained by one player or set of players is lost by another so that the net payoff to all the players is zero. *Non-zero-sum* games allow general payoff amounts. Finally, games may be *non-cooperative* or *cooperative*. In non-cooperative games, each player chooses actions independently to optimize her own payoffs. Cooperative game models represent the actions of groups of players in which cooperation may yield strategic alliances and improved payoffs. The reader is referred to the texts by Osborne (2004) and Gibbons (1992) for comprehensive treatment of different classes of games.

Integral to an understanding of game theory is the concept of Nash equilibrium (Nash, 1950), which is an outcome from which no player can improve his payoff by unilaterally altering his strategy. In other words, no player has incentive to deviate from his strategy even upon observing the strategies of his opponents. Nash equilibria do not necessarily imply optimal payoffs for any player. Instead, they represent the product of decisions made in a player's self-interest and the assumption that other players will do likewise.

3 Competition between Relief Agencies

Non-profit activity has risen sharply over the past century; for instance, the number of registered US non-profit organizations rose from 12,000 in 1940 (Frumkin and Kim, 2001) to more than 1.5 million in 2012 (National Center for Charitable Statistics, 2013). In this setting, competition may emerge between NGOs for media exposure and funds. This section describes game theory models of inter-agency competition. Figure 1 summarizes the topics addressed by each of the papers we survey. While all of the publications identify sources of competition and most discuss negative outcomes that can result, only two sources give specific advice to mitigate these outcomes.

Author	Publication	Sources of Competition	Effects of Competition	Methods for Mitigating Effects of Competition
Castaneda *et al.* (2008)	The Journal of Law, Economics & Organization	X	X	X
Feigenbaum (1987)	The Journal of Industrial Economics	X	X	
Frumkin and Kim (2001)	Public Administration Review	X	X	
McCardle *et al.* (2009)	Decision Analysis	X		
Privett and Erhun (2011)	Manufacturing and Service Operations Management	X	X	X
Tatham and Kovács (2010)	International Journal of Production Economics	X	X	
Wardell (2009)	Ph.D. Dissertation - Georgia Institute of Technology	X	X	
Zhuang *et al.* (2011a)	Annals of Operations Research	X		
	Totals	8	6	2

Figure 1.
Literature on Competition

3.1 Media Exposure

Media presence can cause competition between NGOs as it provides an opportunity to publicize a group and its cause. Research shows that donors are more likely to give to charities they have seen first-hand (Waters and Tindall, 2011) or to those perceived to be productive (Frumkin and Kim, 2001). Therefore, media coverage attracts support (Olsen and Carstensen, 2003) and encourages competition among agencies for service areas with a media presence (Balcik *et al.*, 2010). The media can also be used to "signal" current donors that their money is being well spent in hopes of soliciting future donations (Wardell, 2009). This trend has attracted criticism from researchers who argue too much emphasis on media exposure degrades the quality of service. Wardell (2009) introduces a symmetric game theory model to demonstrate the impact of agencies' desire to signal donors while choosing aid distribution site locations. Each agency's strategy is based upon an objective function combining beneficiary impact and signaling potential. The result of the game is the over-saturation of relief areas in which media coverage is high to the detriment of service in other areas. Wardell asserts that over-saturation wastes resources that would better serve beneficiaries in a different location.

3.2 Methods of Raising Money

In between disasters, NGOs are responsible for supporting themselves financially through donations and grants. In fact, nearly $300 billion are given to charity within the United States each year and nine out of ten people report giving to a charitable organization (Zhuang *et al.*, 2011a). NGOs of similar geographic location and/or sector compete with each other for this money because they share the same donor pool. Increasing competition encourages more of an agency's money to be diverted from charitable goals to fundraising efforts (Feigenbaum, 1987).

Fundraising carries upfront costs and relies on public empathy for a cause, which fluctuates over time (Frumkin and Kim, 2001). This subsection discusses two game-based fundraising strategies utilized by NGOs to raise money. The first system involves the intentional public disclosure of information concerning an NGO's performance and impact. The second type of system rewards donors for their gifts in hopes of capitalizing upon a donor's desire for public acknowledgment.

Information Disclosure

One fundraising tool available to NGOs is the public disclosure of information. The information released by an NGO regarding donations, spending, active projects, and perceived impact is intended to demonstrate its efficiency and effectiveness in comparison to others, resulting in a strategically advantageous public perception. Supply chain decisions directly impact information on money spent and beneficiaries reached, and thus form an important part of the data that agencies have available to disclose. Important questions are how much and what kind of information should be shared. Many donors want to see where money is being spent to understand the relative impact of their donations (Castaneda *et al.*, 2008), but donors may become confused or frustrated by too much information (Zhuang *et al.*, 2011a). There is also the danger of disclosing details about efficient operations to competitors who will replicate them (Frumkin and Kim, 2001).

An objective of the NGO is to maximize donations, but the literature describes several different objectives for donors. These include a desire to feel good about themselves, dubbed the "warm glow" effect (Andreoni, 1990), or to demonstrate their wealth to others (Glazer and Konrad, 1996). Zhuang *et al.* (2011a) posit that people also give because they empathize with a problem and want their donation to maximize service to beneficiaries. They construct an extensive game model between a group of donors and a group of charities to analyze the relationship between information disclosure and charitable donations. The model assumes that donors desire some quantifiable combination of personal publicity and charitable impact from their donation while the charitable organization desires the maximum amount of gifts possible. Experimentation with this game shows a positive correlation between charitable giving and relevant information disclosure. The question of what type of information to disclose is studied by Frumkin and Kim (2001), who analyze charity donations over a ten-year period. Interestingly, the results indicate that charities reporting high financial efficiency did not receive significantly more donations than those who did not. The authors suggest that invoking empathy and demonstrating ability to have an impact may be more beneficial than disclosing information about leanness.

Fundraising Structures

An organization's fundraising structure can also impact its success in competing for donations. One structure is tiered giving, in which organizations assign donations to different tiers corresponding to their amount and donors may receive a tier-specific reward. McCardle *et al.* (2009) argue that this type of system is superior to non-tiered systems using a single-donor model. The players are a charity, which chooses tier levels, and a donor, who chooses a gift amount based upon an objective function that includes warm glow and public acknowledgement. They find that a donor will never decrease his donation when a tiered system is implemented, and that if the next highest tier is sufficiently close, a donor will increase his donation to that tier.

The authors construct a tool for charities to identify tier levels that maximize one-time donations given the estimated wealth distribution of their target market.

Various contract structures for non-profit fundraising have also been modeled using game theory. Castaneda *et al.* (2008) argue for contracting with donors to stabilize an organization's income. They model competition for donations as a three-stage dynamic game between charitable organizations and potential donors. An equilibrium analysis of this model concludes that as charities increase the proportion of expenses paid with donor contracts, less money is put toward promotion and administration expenses, leaving more for charitable goals.

Privett and Erhun (2011) propose contracts that permit donors to audit a non-profit's use of their funds. If tangible benchmarks specified in the donation contract are not achieved, the charity may be charged a penalty that reverts to the donor. The authors apply the principal-agent framework to this scenario. Principal-agent games are extensive games of imperfect information in which the first player (the principal) offers terms to encourage one or more agents to act in the principal's best interest. (See Ross (1973) for an early introduction and Zenios (2004) for an overview of supply chain applications.) In this application, the donor is the principal and the charitable organizations are the agents; each player seeks to maximize his respective utility function. Results indicate that donors and non-profits that report good administrative and operational efficiency would welcome an auditing framework. The authors suggest that auditing would increase efficiency because managers would try to avoid the penalty for poor performance. In contrast, researchers have identified instances where contracts may degrade the quality of service in a disaster response (Besiou, 2012). Such is the case when an immediate need presents itself but the only available resources have been contracted for other purposes.

4 Cooperation between and within Relief Agencies

Though competition exists between NGOs, the altruistic nature of humanitarian relief attracts personnel with common goals who are willing to work together (Jie, 2008). The commercial supply chain literature suggests numerous advantages of cooperation between agents (see Arshinder *et al.* (2008) and Cachon and Netessine (2006) for reviews), many of which also have parallels in the humanitarian context. As shown in Figure 2, the literature contains numerous articles that describe motivations for inter-agency and intra-agency cooperation, the most obvious of which is the positive effect it may have on beneficiaries (Coles and Zhuang, 2011). Partnering NGOs may identify service gaps by comparing their respective locations, resources, and limitations. Furthermore, partnering agencies are able to focus on core competencies (Jahre and Jensen, 2010, Schulz and Blecken, 2010), capitalize on economies of scale in purchasing and transportation (Cruijssen *et al.*, 2007), and utilize shared warehouse space for pre-positioned goods (Schulz and Blecken, 2010). Cooperating NGOs may also reduce costs by consolidating administration, standardizing measurements, and adopting common policies (Schulz and Blecken, 2010).

This section discusses NGO cooperation from a game theoretic perspective. Though agency cooperation is especially beneficial in the humanitarian sector, its mathematical study is relatively new. Here we describe models that emphasize specific opportunities for cooperative efforts and then discuss obstacles to cooperation in practice. In total, we survey 20 articles concerning cooperation; the topics addressed by each article are summarized in Figure 2. While most articles propose reasons for and/or barriers to cooperation, it is encouraging to note that 77 percent of those that discuss obstacles also suggest methods to improve cooperation.

Author	Publication	Motivations for Cooperation	Barriers to Cooperation	Methods for Improving Cooperation
Bagchi *et al.* (2011)	International Journal of Production Economics	X	X	X
Balcik *et al.* (2010)	International Journal of Production Economics	X	X	X
Coles and Zhuang (2011)	Journal of Homeland Security and Emergency Management	X	X	X
Coles and Zhuang (2013)	Working paper		X	X
Coles *et al.* (2012)	Socio-Economic Planning Sciences	X		
Cruijssen *et al.* (2007)	Transportation Research Part E: Logistics and Transportation Review	X	X	X
Ergun *et al.* (2013)	Production and Operations Management	X		X
Hasija (2012)	Proc. of 23rd Annual POMS Conference	X	X	X
Heier Stamm *et al.* (2013)	Working paper	X		X
McLachlin and Larson (2011)	Journal of Humanitarian Logistics and Supply Chain Management	X	X	X
Moore and Heier Stamm (2012)	Proc. of 2012 Industrial and Systems Engineering Research Conference	X		X
Natsios (1995)	Third World Quarterly		X	
Overstreet *et al.* (2011)	Journal of Humanitarian Logistics and Supply Chain Management		X	
Proaño *et al.* (2012)	Omega	X	X	X
Schulz and Blecken (2010)	International Journal of Physical Distribution and Logistics Management	X	X	X
Stewart *et al.* (2009)	International Journal of Physical Distribution and Logistics Management	X		X
Tatham and Kovács (2010)	International Journal of Production Economics	X	X	X
Thevenaz and Resodihardjo (2010)	International Journal of Production Economics		X	
Trestrail *et al.* (2009)	International Journal of Physical Distribution and Logistics Management	X		X
Zhuang *et al.* (2011b)	Proc. of 2011 NSF Engineering Research and Innovation Conference	X		X
	Totals	16	13	16

Figure 2.
Literature on Cooperation

4.1 Opportunities for Cooperation

For humanitarian logisticians, cooperative models identify methods for partnering agencies to achieve greater impact than what is possible when operating independently. Prior research also investigates conditions under which inter-agency cooperation would be welcomed by supply chain players and introduces intra-agency cooperative practices to improve operations.

Procuring supplies and transportation services often involves interactions between multiple humanitarian supply chain parties (Bagchi *et al.*, 2011, Hasija, 2012). For example, the US Department of Agriculture (USDA) utilizes a bidding process in which domestic suppliers of international food aid and ocean carriers submit separate bids for their services. Upon receiving both sets of bids, USDA uses a linear program to select the lowest cost supplier-carrier pairings to transport procured food. The current system is argued to motivate bids that are much higher than actual costs, decreasing the amount of food aid that USDA is able to purchase (Bagchi *et al.*, 2011). Trestrail *et al.* (2009) recommend the adoption of a uniform price auction, an approach shown to keep winning bids closer to actual costs. If USDA implements the new system, Bagchi *et al.* suggest that synergetic suppliers and carriers form partnerships with each other *a priori*, leading to lower joint bids that reflect the benefits of cooperation. Savings from lower bids could increase the amount of food aid that USDA can send to beneficiaries.

Another example of the potential for increased impact through cooperation is documented by Moore and Heier Stamm (2012), who quantify the impact of the absence of coordinated facility location decisions on cholera treatment accessibility in Haiti. Optimal treatment facility locations are identified using an integer programming model that maximizes access. The results indicate that coordinated facility location decisions may have led to significant improvements in treatment accessibility in comparison to actual decisions made by NGOs acting independently. To close this gap, the authors propose future work in a cooperative game framework to identify mechanisms that lead to independent decisions that optimize access to beneficiaries.

Research by Ergun *et al.* (2013) and Proaño *et al.* (2012) emphasizes conditions under which multi-agency cooperation is beneficial and acceptable to the organizations involved. Motivated by a successful partnership between the United Parcel Service (UPS) and The Salvation Army in Haiti that led to improved operations in a camp for internally displaced persons, Ergun *et al.* (2013) introduce a cooperative game theory model to analyze technology-enabled coordination among agencies. The players are camp management agencies, each of which must decide whether to adopt an electronic registration system and collaborate with other camps. Since adoption requires a significant investment, agencies' choices depend on how the costs are allocated among them. The authors identify conditions under which there exists a cost allocation mechanism that incentivizes all agencies to collaborate. Proaño *et al.* (2012) study beneficiary access to vaccines as a game between vaccine manufacturers and purchasing countries. The model produces vaccine prices that maximize manufacturer profits while meeting vaccine demand. To combat unfair outcomes, the researchers suggest that a third player, such as the World Health Organization, the Pan American Health Organization, or the United Nations Children's Fund, use the model to negotiate fair prices with vaccine producers. In this instance, vaccine manufacturers may experience lower net profit, but if they share the objective to maximize vaccination coverage, cooperation may produce beneficial solutions for all.

Within a single agency, separate divisions and country offices may have different incentives and objectives, making supply chain coordination across the agency difficult. One approach is to adopt a centralized system, in which a single decision maker or group controls supply chain operations. Such systems have the advantage of standardized practices and can consider what is best for the whole system. Unfortunately, some have performed sluggishly in disaster response. For instance, the International Federation of Red Cross and Red Crescent Societies (IFRC) formerly utilized a centralized supply chain based out of their headquarters in Geneva, Switzerland. When Hurricane Mitch struck Honduras in 1998, IFRC initiated relief operations no less than two weeks following the disaster, long after other agencies had established themselves. The delay was blamed on an inefficient aid request process in which information had to navigate several channels to reach the centralized decision maker (Gatignon *et al.*, 2010).

In contrast to the centralized approach, decentralized systems rely upon multiple decision makers, each controlling smaller amounts of resources within a subsystem. Decentralized systems benefit from strategies better suited to local conditions since decision makers are closer to affected populations (Thevenaz and Resodihardjo, 2010). IFRC, for example, restructured its supply chain in 2005 and adopted a decentralized system that split global operations into three Regional Logistics Units, each with its own headquarters and prepositioned goods. The perceived advantages of the new system included faster response time, better communication of needs, and local expertise. The new supply chain was tested after the 2006 earthquake in Yogykarta, Indonesia. The response was much faster and economical than past efforts. In general, coordination problems can become significant when local decision makers lack global information or visibility regarding the effect of their decisions on the system as a whole. This may result in duplicated work and misallocation of resources (Thevenaz and Resodihardjo, 2010). Regardless of the level of decentralization, coordination of efforts is essential within an agency's supply chain to maximize performance.

4.2 Barriers to Cooperation

Given the potential benefits, what is stopping improved cooperation between NGOs? The initial barriers often result directly from the nature of disaster relief. The urgency of many response environments hinders an agency's ability to coordinate with others as it requires valuable time and human resources (Balcik *et al.*, 2010). Damage to communication and transportation infrastructure compounds the problem by inhibiting coordination when partnerships do form (Maiers *et al.*, 2005).

As a response stabilizes, agencies have difficulty finding partners with compatible objectives, practices, and resources (Cruijssen *et al.*, 2007). NGOs often utilize distinct systems for managing their resources and handling data (Balcik *et al.*, 2010, Moshtari and Gonçalves, 2012), which results in software incompatibility (Overstreet *et al.*, 2011) and varying units of measurement (Balcik *et al.*, 2010). Zhuang *et al.* (2011b) and Coles *et al.* (2012) explore the partnerships that emerged in response to the 2010 Haiti earthquake. Interestingly, data indicate that the most effective partnerships were based on new contacts rather than previously existing relationships with local agencies. In this response, NGOs actively compared alternatives when selecting local partners with compatible objectives (McLachlin and Larson, 2011). This research underscores the importance of NGOs seeking optimal partnerships and enduring the necessary relationship-building required. Game theory can be used to identify a beneficial partnership, as in

Coles and Zhuang (2013), who construct an extensive game that models behavior between two agencies deciding to collaborate or not. The model integrates a probability that any two agencies will be compatible, every partnership is assumed to require an initial investment, and successful partnerships yield a greater benefit than cost. The authors propose extending the model to *n* players, enabling compatible partnership formation on a larger scale.

Issues of trust and power also present barriers to cooperation. The competitive nature of humanitarian relief can hinder trust formation between NGOs (Moshtari and Gonçalves, 2012, Schulz and Blecken, 2010, Tatham and Kovács, 2010). Upon a conscious decision to combine efforts, agencies may suffer hierarchal power disputes (Balcik *et al.*, 2010, Natsios, 1995). Small agencies may fear losing their sovereign identity upon partnering with a large agency that may receive the bulk of visibility and credit, as well as being pushed out of the partnership once their resources are no longer necessary (Cruijssen *et al.*, 2007).

5 Humanitarian Relief and Governmental Authorities

Government and military entities participate in and impact many humanitarian operations. Two of the most frequent humanitarian contexts in which governmental and non-governmental organizations interact are in cases of population displacement across borders and in settings where both NGO and military groups operate. Game theory provides tools to model the interactions between governmental and non-governmental decision makers, who may have conflicting objectives. Games are also used to model government investments in disaster defense.

5.1 Interactions between Governmental and Non-governmental Organizations

Natural and manmade disasters often force refugees to seek shelter across proximal borders. Governmental authorities retain the power to open and close borders to refugees and relief agencies alike. Prospective host governments often request support from the United Nations High Commissioner for Refugees (UNHCR), the North Atlantic Treaty Organization (NATO), and other countries to assist arriving refugees. Games are useful in investigating motives, explaining decisions, and predicting outcomes of these interactions. Generally players include a country of asylum, a country of repatriation, and a group of refugees or their representative (NATO or UNHCR).

Researchers have chosen the Theory of Moves (TOM) to model many such circumstances. Originally defined by Brams (1994) and revised by Wilson (1998), TOM is an extensive game framework with perfect information in which players sequentially make changes in strategy until all players decide to pass, at which point the game is at equilibrium. This process mirrors lengthy political negotiations in which agents make offers and counter-offers. TOM has been utilized to model the situations faced by Rwandan, Indochinese, and Albanian refugees, in particular. The primary contribution of the Rwandan model (Zeager, 1998) is its examination of sympathetic versus non-sympathetic countries of asylum, where the level of sympathy is reflected in a country's utility function and depends on economic and cultural compatibility. The results of the paper indicate that varying levels of sympathy may alter a government's decision to help or not. The same author uses TOM to model the plight of Indochinese refugees immediately following the Vietnam War (Zeager, 2002). The players in the game include Thailand and the US; Thailand's actions are to permit or deny asylum, while those of the US are to permit or deny

resettlement. In actual negotiations, Thailand threatened to refuse asylum unless the US offered resettlement. Zeager's analysis demonstrates the impact of one player's power to end the game at a mutually disadvantageous outcome and the ways that TOM can provide insight about this threat power.

Comparing actual outcomes with those predicted by game theory models points to ways in which modeling approaches can be improved for future applications. Williams and Zeager (2004) model the 1998 crossing of ethnic Albanian refugees from Kosovo into Macedonia as a game between Macedonia and NATO. Macedonia's available actions are to open or close its borders, while NATO decides whether to commit only financial assistance or to provide asylum assistance as well. The equilibrium solution, in which NATO provides only financial assistance and Macedonia keeps its borders closed, is the worst possible outcome. The actual outcome, in which NATO also provided asylum assistance and Macedonia opened its borders, differed from the one predicted by the model due to the influence of third parties not explicitly represented in the game, including UNHCR, journalists, and the US Department of State.

NGOs frequently interact with militaries of both host country and foreign governments. Countries may commit military resources to ensure security or execute humanitarian supply chain functions. NGOs and military units sometimes participate in the same missions, wear the same clothing, and drive the same vehicles, making humanitarian personnel indistinguishable from soldiers (Olson, 2006). Furthermore, some NGOs actively utilize military resources because military groups are known for being organized, well trained, and able to command extensive supply networks. In some cases, coordinated operations between NGOs and military forces may reach more people. Host governments, for instance, are often the first responders to disasters within their borders (Heaslip *et al.*, 2012). Military forces add a level of complexity to humanitarian environments because, while a partnering NGO may achieve greater effectiveness by utilizing military resources, the partnership may negatively impact public perception of the NGO's neutrality. IFRC realized this during humanitarian operations in Pakistan after an earthquake in 2005. Despite having access to over 100 military helicopters to transport aid, IFRC chose to hire their own aircraft at greater expense to avoid conflict with their principles of humanity, independence, and neutrality, especially in the politically tense region (Heaslip *et al.*, 2012). In such circumstances, decision models offer the ability to evaluate tradeoffs between conflicting objectives such as cost and neutrality.

5.2 Government Investment in Disaster Defense

Nations have a vested interest in preparing for and mitigating the impact of disasters. Much research has applied game theory to questions of defense against disasters caused by acts of terrorism; these models fall into a class called attacker-defender games (see Brown *et. al.*, 2005, for an introduction). One paper in this stream of literature simultaneously considers investments in defense against terrorism and natural disasters. Zhuang and Bier (2007) model a defender preparing for an unknown attack that may originate either from terrorists who have knowledge of the system or from a natural disaster of random force and location. The defender chooses the proportion of his budget to invest in protection from these two types of events. An equilibrium solution is the budget allocation that makes both attacker and defender indifferent to the type, location, and strength of an attack.

While the model was designed for use in protecting a set of targets, it could be extended for humanitarian supply chain managers who wish to adapt a defensive perspective. Disruptions

to humanitarian supply chains carry a much higher penalty than their commercial counterparts because lives may literally hang in the balance (Kovács and Tatham, 2011). Game theory can be applied to guide decisions about investments in security and stability and allow supply chain managers to prepare for natural and man-made disruptions.

6 Models of Individual Beneficiaries

Most models in the literature capture decisions by governmental or non-governmental organizations. Beneficiaries also act according to individual objectives and available information, and their choices impact humanitarian supply chain operations and public health campaign outcomes. For instance, beneficiaries commonly must choose which facility to visit for services or relief supplies. Classic models of facility location and resource allocation rely upon the assumption that consumers are either assigned to a facility or that they will visit the closest one (Daskin, 1995, De Palma *et al.*, 1989). In reality, centralized assignment is often not possible, and beneficiaries may consider factors besides distance. Game theory models that explicitly capture beneficiary decisions demonstrate the impact that decentralization can have on system outcomes (Heier Stamm, 2010, Heier Stamm *et al.*, 2013). If supply chain managers begin integrating results from decentralized models, they may more accurately predict beneficiary decisions, improving aid utilization and beneficiary access.

Individuals' choices about health, such as whether or not to be vaccinated against an infectious disease, can also impact their community at large. Vaccination confers a direct benefit to those vaccinated, but as more people receive vaccinations, those who remain unvaccinated indirectly benefit from the lower probability of being infected. Shim *et al.* (2012) model a community of individuals, each deciding whether to vaccinate himself against influenza or not. The outcomes emphasize the dramatic difference in vaccination levels that emerge when decision makers are completely self-interested and when levels of altruism are introduced to an individual's objective function. This research demonstrates the potential for models to help identify opportunities to influence individual utility functions in a way that improves human outcomes.

7 Summary of Findings and Directions for Future Research

This paper summarizes literature that applies game theory to humanitarian operations. The interactions of independent decision makers within this sector provide an ideal setting for the application of game theory to optimize strategy and improve operations. The main finding of this paper is that while there have been promising steps toward an integration of game theoretic concepts, the humanitarian relief community has access to only a few practical tools. The enormous consequences of supply chain performance in the humanitarian sector further strengthen the argument for its mathematical study. Because there has not been a literature review of game theory's application to humanitarian supply chains, this work serves as a reference of current literature while discussing directions for future research.

7.1 Summary

To identify gaps in existing research, we categorize each article according to the facet(s) of humanitarian response to which it corresponds, as summarized in Figure 3. If the paper

describes a game theory model, we denote that in the "Game Model" column. Since decentralization in humanitarian environments makes game theory a particularly important tool, we also denote papers that explicitly discuss decentralization. The "Supply Chain Operations" category includes 40 percent of the papers; these papers deal with the physical distribution of aid. Papers indicated in the "Planning and Strategy" column constitute 37.1 percent of those surveyed. These address topics that affect an NGO in the preparedness phase of disaster response, including methods for improving efficiency and security as well as identifying potential political actions. Lastly, the category labeled "Administration and Donations" refers to the 28.6 percent of papers we survey that provide insight for supply chain managers about administrative functions and soliciting donations.

Of the 35 articles listed in Figure 3, 18 include an explicitly modeled game. This supports the claim that, while there are opportunities for game theory to be applied to humanitarian logistics, few existing studies have done so. This becomes even clearer when one considers that 40 percent of all the papers we survey focus on supply chain operations that can benefit from game theoretic analysis, yet only 16.6 percent of the papers that include game theory models address this aspect. Planning and strategy papers constitute 44.4 percent of those with models, while sources emphasizing administration and donations contribute 33.3 percent. Decentralization is the focus of 16.6 percent of those papers that include games. Among the major game theory model categories, extensive form games are well-represented in the current literature. These are used to represent interactions between charities and donors, the formation of partnerships between NGOs, bidding by suppliers and carriers, negotiation processes, and attacker-defender scenarios.

Author	Publication	Game Model	Centralized vs. Decentralized Supply Chains	Supply Chain Operations	Planning and Strategy	Administration and Donations
Andreoni (1990)	The Economic Journal					X
Bagchi *et al.* (2011)	International Journal of Production Economics	X	.		X	
Balcik *et al.* (2008)	Journal of Intelligent Transportation Systems			X		
Balcik *et al.* (2010)	International Journal of Production Economics			X	X	
Besiou (2012)	Proc. of 23rd Annual POMS Conference		X			X
Brams (1994)	American Scientist	X			X	
Castaneda *et al.*(2008)	The Journal of Law, Economics & Organization	X				X
Coles and Zhuang (2011)	Journal of Homeland Security and Emergency Management			X		
Coles and Zhuang (2013)	Working paper	X			X	
Coles *et al.* (2012)	Socio-Economic Planning Sciences			X		
Ergun *et al.* (2013)	Production and Operations Management	X		X		
Feigenbaum (1987)	The Journal of Industrial Economics					X

Frumkin and Kim (2001)	Public Administration Review					X
Gatignon *et al.* (2010)	International Journal of Production Economics		X	X		
Glazer and Konrad (1996)	The American Economic Review	X				X
Hasija (2012)	Proc. of 23rd Annual POMS Conference		X	X		
Heier Stamm (2010)	Ph.D. Dissertation - Georgia Institute of Technology	X	X	X		
Heier Stamm *et al.* (2013)	Working paper	X	X			
McCardle *et al.* (2009)	Decision Analysis	X				X
McLachlin and Larson (2011)	Journal of Humanitarian Logistics and Supply Chain Management				X	
Moore and Heier Stamm (2012)	Proc. of 2012 Industrial and Systems Engineering Research Conference	X	X	X		
Natsios (1995)	Third World Quarterly			X		
Overstreet *et al.* (2011)	Journal of Humanitarian Logistics and Supply Chain Management			X		
Privett and Erhun (2011)	Manufacturing and Service Operations Management	X				X
Proaño *et al.* (2012)	Omega	X			X	
Stewart *et al.* (2009)	International Journal of Physical Distribution and Logistics Management				X	
Tatham and Kovács (2010)	International Journal of Production Economics			X		
Thevenaz and Resodihardjo (2010)	International Journal of Production Economics		X	X		
Wardell, (2009)	Ph.D. Dissertation - Georgia Institute of Technology	X				X
Williams and Zeager (2004)	Conflict Management and Peace Science	X			X	
Zeager (1998)	International Studies Quarterly	X			X	
Zeager (2002)	Rationality and Society	X			X	
Zhuang and Bier (2007)	Operations Research	X			X	
Zhuang *et al.* (2011a)	Annals of Operations Research	X				X
Zhuang *et al.* (2011b)	Proc. of 2011 NSF Engineering Research and Innovation Conference			X	X	
	Totals	18	7	14	12	10

Figure 3.
Summary of Literature

7.2 Research Opportunities

We see important opportunities for increased use of game theory models in humanitarian operations in general and, in particular, for studies applying cooperative and imperfect information games. In addition to these broad observations, we describe a number of specific opportunities for game theory models to provide insight to humanitarian operations.

Disasters often damage communication networks, making reliable information difficult to obtain. However, a successful response relies upon accurate information about demand, supply, and available transportation routes. Generally, NGOs do not allocate substantial time or resources to share information (Balcik *et al.*, 2010). Because reliable information is so valuable, there exist strategic advantages to those who control its flow and incentives for agencies to compete for exposure to information flow (Maiers *et al.*, 2005). Information is also a critical element in cooperative efforts. One potentially useful modeling framework is built on the notion of network centrality, where an agency's centrality score quantifies how integral an agency is to information flow. Scores are calculated using a network model; nodes represent agencies and edges between pairs of nodes are weighted to represent the amount of information flowing between them. Network centrality has been used to model inter-agency communication during the responses to the 2000 Mozambique floods (Moore *et al.*, 2003) and to the September 11th, 2001, terrorist attacks (Kapucu, 2005). The former paper finds a positive association between agency centrality scores and beneficiaries reached, which is attributed to the level of information access. Future research could quantify the strategic advantage of information access, benefits and costs of sharing information among agencies, and mechanisms to allocate benefits and costs.

Future research could advance the community's understanding of desirable and undesirable effects of media exposure. Is there empirical data to suggest that relief operations have been negatively affected in the past? If so, are there mechanisms that eliminate detrimental competition while conserving the benefits of media exposure? Are there policies that may ensure equitable access for beneficiaries in the presence of the media? How is the notion of media exposure changing with the rapidly increasing availability of smart phones and crowdsourcing of news?

While there is work concerning mechanisms for maximizing donations, there has been little research conducted on other ways that charities can obtain revenue. Some non-profits have begun auctioning goods and services. In fact, Bidding for Good (www.biddingforgood.com) has raised over $160 million for 6,200 non-profit organizations through online auctions. Similar websites include Charity Buzz (www.charitybuzz.com) and Ready Set Auction (www.readysetauction.com). These sites provide powerful tools for NGOs to raise money with minimal upfront investment. However, there has been little analysis done to optimize their use. How does altruism affect bidding? What type of auction structure serves the NGO best? What types of goods maximize the profit margin?

Considering the enormous rise in the number of non-profits, charities who want to survive must find a niche. Game theory offers tools to identify untapped markets in the presence of competition. Given an initial set of non-profits and their donors' behavior, how can a new organization find donors to build a cash flow? The Stackelberg model, a classic extensive game in which a new entrant to the market can observe a competitor before deciding upon his own strategy, may be modified to provide insight for this situation.

There exist numerous opportunities for research to guide cooperative relationships among NGOs, between NGOs and government or private entities, and within agencies. The literature

points to the consequences of poor coordination, including duplicated work and under-served beneficiaries. While qualitative guidance is offered, for example, to encourage standardization and synergetic partnerships, quantitative models to inform and support cooperation are lacking. Future cooperative models may help NGOs find complementary partners, quantify the costs and benefits of a partnership, and determine a fair allocation of resources to optimize mutual goals. Balcik *et al.* (2010) suggest the formation of supplier-buyer alliances to improve aid procurement through bulk-buying and shared shipping costs. Stewart *et al.* (2009) suggest that non-profits partner with private businesses to improve a community's resiliency to disasters. Research efforts could also lead to approaches that combine facets of centralization in some areas and decentralization in others. Game theory offers a powerful framework for understanding and improving cooperation in the humanitarian context, where each link in a supply chain has a unique perspective and expertise.

Each humanitarian response occurs within a particular political context, meaning that the motivations and actions of political actors shape the response environment. This is true whether the entity in question is a host country government, foreign government, military authority, or militant group. When a government or military organization engages in relief operations, they bring a host of resources and skills. On the other hand, political realities also mean that the safety of humanitarian personnel is a major concern in some regions. For instance, 90 aid workers were murdered in Afghanistan alone between 2003 and 2006 (Olson, 2006). Games provide a tool to model ways that objectives and actions of political entities may impact humanitarian supply chain operations. Future research could lead to models that enable humanitarian logisticians to identify potential threats and vulnerabilities and develop strategies to increase supply chain security.

Much work remains in the creation of models that integrate decentralized beneficiaries' decisions. Future models may incorporate parameters besides distance and facility congestion, such as human behavior and social networks. For instance, more accurate demand estimates for public health emergencies may be generated via disease transmission models that use game theory to account for human decisions, such as that described by Wu *et al.* (2013). Furthermore, integrating beneficiary decision models with agency models in a comprehensive framework could significantly advance our understanding and management of humanitarian supply chain systems.

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