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Bridging the research-practice gap in disaster relief: using the IFRC Code of Conduct to develop an aid model

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Abstract Bridging the gap between research and practice has been a recognized problem in many fields, and has been especially noticeable in the field of disaster relief. As the number and impact of disasters have increased, there has been a jump in interest from the research community in an attempt to provide tools and solutions for some of the challenges in the field. The International Federation of Red Cross and Red Crescent Societies (IFRC) Code of Conduct (CoC) for Disaster Operations provides a qualitative set of guidelines that is an excellent building block for operational theory, but is insufficiently rigorous in guiding quantitative decision making. In this paper, we review the CoC, exploring each of the ten core principles and identifying three significant operational trade-offs. We then propose a model framework that can be implemented as a stand-alone model, or can be used as a foundation for other quantitative aid allocation models. Finally, we provide an example of how the proposed model could be used to guide decision making in a Microsoft Excel® environment using CoinOR's OpenSolver®. New insights in the field of aid disbursement are provided by examining the challenges of financial management and investment as dictated by the CoC. This paper fills a unique gap in the literature by addressing the issue of financial allocation as guided by a qualitative standard used by the disaster relief community, and serves as a complement to the work in the field of humanitarian logistics.

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1 Introduction

Bridging the gap between research and practice has been a recognized problem in many fields, and has been especially noticeable in the field of disaster relief (Altay and Green 2006; Kovacs and Spens 2011). As the number and impact of disasters have increased, there has been a jump in interest from the research community in an attempt to provide tools and solutions for some of the challenges in the field. However, the rapid increase in research by academics has not always been guided by an understanding of the complex and nuanced challenges faced by people working in disaster relief. In this paper, we attempt to bridge this gap by taking the goals defined in the International Federation of Red Cross and Red Crescent Societies (IFRC) Code of Conduct (CoC) and putting them in terms that are usable by modelers and researchers working to help improve disaster relief operations (Red Cross Federation 1994).

When providing solutions to a relief organization, or supporting operational efficiency in distribution, it is essential that the guidelines and values of that context are captured in any problem formulation. Because of the variety and complexity of humanitarian relief operations, a cohesive and standard set of principles or approaches has not yet been adopted by the operations research and management science community for how to formulate problems. In this paper we develop a model for aid disbursement directly from the Red Cross CoC as an example of how effective solutions could be designed for humanitarian relief problems.

In this paper, we look at the CoC in detail and identify the trade-offs in the IFRC-CoC. We discuss how each qualitative constraint could be converted into a quantitative metric for assessment and decision-making, and augment the model to add a control variable for each conflict in qualitative requirements to provide a basic model which is built on the qualitative principles for disaster researchers of the disaster relief community.

The rest of the paper is organized as follows. Section 2 gives the motivation and background of this paper, discusses disaster codes and standards, as well as reviews current models for disaster aid management and delivery. Section 3 analyzes the principles of the CoC, and lists the notation that will be used throughout the paper. Section 4 builds the mathematical model. Based on the discussion of the previous sections, Sect. 5 illustrates a practical example. Finally, Sect. 6 discusses the future research directions and concludes the paper.

2 Problem motivation and background

Professional codes of ethics or conduct are used in several disciplines such as engineering (e.g., National Society of Professional Engineers Code of Ethics) (National Society of Professional Engineers 2007) and medicine (e.g., Hippocratic Oath) (Hulkower 2010). When these codes are violated, and that violation is brought to light, there can be professional and legal consequences: when a beam fails in a building, or a patient dies in a hospital, the responsible party can be identified and will likely suffer some loss as a direct result of the failure. Although there are some enforcement mechanisms in certain countries (e.g., 501(c)(3) regulation in the United States), these mechanisms are often problem-specific (e.g., the Internal Revenue Service watches for financial mismanagement) rather than checking for overall organizational efficacy (Shapiro 1997; Esty 1998; Guay et al. 2004).

In 1994, the IFRC worked with some of the largest Non-Governmental Organizations (NGOs) working in disaster relief to agree on a set of principles to guide disaster relief operations. This set of principles is referred to as the CoC and provides organizations involved in disaster relief with a set of expectations and objectives for behavior in a relief operation. The code is non-binding and is designed to help organizations self-assess and refocus disaster relief operations. Additionally, the code provides a list of standards that could be used to assess a potential partner to ensure operational excellence and make sure that investments in relief are conducted with the utmost integrity.

2.1 Discussion of disaster codes and standards

In order to minimize abuses in the world of humanitarian aid, there have been several creative approaches to monitor NGO operation and aid dispersement, since there are few formal enforcement mechanisms. Although there are malicious (e.g., hacking) or "shame-based" (e.g., news articles, political inquiry) methods of keeping aid organizations accountable, the most respected approach to aid assessment is achieved by formal entities which assess organizations like Charity Watch and Givewell (Lowell et al. 2005). Unfortunately, some of the metrics that have been adopted to monitor an organization's efficacy (e.g., percent of budget used for administration) can result in aid being less effective in the long-run (Eckhart et al. 2013).

In this paper, we take a novel approach to disaster model development by using an accepted set of "industry standards" as the guide for developing a linear program to optimize aid disbursement. Though there are several standards and codes that apply to aid disbursement and disaster relief, the CoC is of particular interest because it examines the methodology of operations rather than just a minimum goal (e.g., the SPHERE standards) or an overarching philosophy (e.g., the Seven Fundamental Principles of the IFRC).

The Sphere Handbook provides a "humanitarian charter and minimum standards in humanitarian response" (Andre and Collins 2001), and is comprised of a set of minimum expectations for how to meet the needs of people in a disaster relief scenario (Andre and Collins 2001). While some of the standards address overarching policy, many of the standards are more specific requirements meeting the needs of aid recipients (e.g., the amount of water per day, per person, number of latrines for 1000 people). The Sphere Handbook (Sphere Project 2011) would also be an interesting case for optimization analysis, but would be much more situationally dependent if encoded in a model. However, the CoC is broad enough within the context of disaster relief that a general model framework could be applied in any relief context rather than in only one particular type of situation.

Humanity, Impartiality, Neutrality, Independence, Voluntary Service, Unity (i.e., partnership), and Universality (i.e., equality among partnering organizations) are the Seven Fundamental Principles (SFPs) of the Red Cross Red Cross Federation (1965). The CoC is different from the SFPs because the CoC is specifically for disaster relief, while the SFPs are a broader set of guidelines for the IFRC as a whole, and are used to help ensure that the actions of the IFRC are in line with the broader mission of the organization. The SFPs are useful when attempting to understand the proper context and use of the CoC, especially to balance objectives that appear to conflict (Ebrahim 2003; Hilhorst 2005).

2.2 Current models for disaster aid management and delivery

Here we review some of the ways that different models have been proposed for application in a disaster relief environment, pointing out potential weaknesses and providing context for the work presented.

Sahana was developed in that aftermath of the Indian Ocean tsunami in 2004 (Currion et al. 2007), and is one of the most well-known platforms for disaster management. There have also been a number of interesting approaches proposed for near real-time disaster management using social media (Birkmann 2006; Sutton et al. 2008; Gao et al. 2011; Yates and Paquette 2011). In this study, we focus primarily on interagency modeling, a topic which has received much less attention in literature.

Whenever a solution is provided or recommended to an organization, it is essential that the objectives and constraints match the goals and limitations of the problem and organizational context. One of the most common approaches in the literature for developing metrics and methodologies for relief distribution is to take a method used in commercial supply chains and attempt to find parallel applications in disaster relief or humanitarian logistics. For example, Beamon and Balcik (2008) provide an overview for how commercial supply chain performance metrics could apply to disaster operations, but stop short of providing a clear application for how such metrics could practically be implemented. While there is some literature that looks at comparing aid investment to measure cost effectiveness (Sperling 2002; Khan and Ahmed 2003), there is much room for growth and improvement.

Coordination is very difficult to achieve in a disaster context (Bryant and Lindenberg 2001; Moore et al. 2003; Stephenson 2005; Stephenson and Schnitzer 2006) despite the importance of effective coordination in the disaster context (Lee 2000; Simatupang et al. 2002). Some of challenges in the relief environment are that the roles and contributions of a relief agency may be unclear when a government is dysfunctional (Seaman 1999) and a relief agency's true customer is often their donor group rather than the disaster survivors (Kent 1987). The interactions among agencies surrounding disasters have been studied using game theory (Zhuang et al. 2014; Hausken and Zhuang 2016; Xu and Zhuang 2016). Xu and Beamon (2006) use a scoring method to analyze how seven different supply chain mechanisms that are used in commercial logistics might work in a disaster context. Xu et al. (2016) provide an analysis of modeling and mitigating the effects in supply chain disruption using a defender-attacker game. Xiang and Zhuang (2016) study the shortage of essential medical resources in large-scale disasters and provide a queueing network to optimize resource allocation in order to improve the quality of disaster relief operations. This paper uses the CoC as a guide for how to deal with these challenges and build a framework for aid allocation.

Three of the most common topics in optimization and disaster relief are routing problems and logistics problems (Barbarosoğlu et al. 2002; Barbaroso and Arda 2004; Tzeng et al. 2007; Vitoriano et al. 2009), inventory problems (Beamon and Kotleba 2006; Clay Whybark 2007), and facility location problems (Balcik and Beamon 2008; Rawls and Turnquist 2010). Smilowitz and Dolinskaya (2011) provide a broad overview of decision tools that have been proposed for disaster relief operations. Many of the models presented have been linear programming models with single objectives (e.g., cost minimization, impact maximization), but there have been a few that explored aid disbursement while accounting for multiple objectives like cost, efficacy, and probability of success (Balcik et al. 2008; Vitoriano et al. 2009, 2011). With the expansion of the body of literature on methods for aid placement and disbursement, there has been a drive to improve the structure of the objective functions used in the aid models. The drivers for these objective functions usually center around the concepts of equity and efficacy as measured in a variety of creative ways (Tzeng et al. 2007).

Optimization proves extremely useful in the disaster context if applied correctly. Work in optimization has proven insightful in many areas including development of emergency evacuation routes (Sbayti and Mahmassani 2006; Yi and Özdamar 2007), scheduling/transportation problems (De Angelis et al. 2007), relief delivery problems (Tzeng et al. 2007; Yan and Shih

2009), and facility/supply location problems (Mete and Zabinsky 2010; Rawls and Turnquist 2010).

This paper builds on the work that has been done in the field of operations research and humanitarian logistics by building optimization models and exploring a new set of considerations and constraints that are key to successful decision making when dispersing aid. We provide new insight in the field of aid disbursement by examining the challenges of financial management and investment as dictated by the CoC. This paper fills a unique gap in the literature by identifying the trade-offs in the IFRC-CoC, converting qualitative constraints into quantitative metric for assessment and decision-making, and addressing the issue of financial allocation as guided by a qualitative standard used by the disaster relief community, and serves as a complement to the work in the field of humanitarian logistics.

3 Codifying the Code of Conduct

Qualitative standards can provide insight and direction to a decision-maker, but when considering resource allocation problems with direct trade-offs, a quantitative framework can serve to support more effective decision making. In this section, we look at the CoC in detail and discuss how each qualitative constraint could be converted into a quantitative metric for assessment and decision-making. Since we deal with a set of qualitative statements it is important to account for any overlap or conflicts that may not be overtly stated. The identification of trade-offs in the IFRC-CoC is essential to designing a useful and correct model. Here we augment the model to add a control variable for each conflict in qualitative requirements. This approach provides the decision-maker with maximum flexibility when allocating resources in a disaster environment, or developing a new relief program.

3.1 Analyzing the principles and trade-offs

In this section, we review each of the ten principles of the CoC and then discuss how to utilize the principle in a problem formulation in a consistent manner. After discussing the individual principles, we list the trade-offs that must be accounted for in a quantitative modeling framework.

Principle 1: The humanitarian imperative comes first. From this principle, it is clear that a model designed to assist in a disaster context should be focused on assisting people. In accordance with this principle, we propose that the objective function in a humanitarian aid model should always maximize the amount/efficacy of aid/assistance that can be achieved with a constrained budget. Cost minimization may be appropriate as a sub-problem in a larger relief context once a project objective has already been set, but does not appear to be consistent for broader humanitarian models. In cases where there is a clear bound on the amount of aid or efficacy of the project, it is appropriate to use cost minimization as the objective.

One way to offset the change of the objective function from cost to impact is to include a constraint that reduces the impact according to some coefficient for each dollar spent on the project. This would be similar to a Return on Investment (RoI) problem, where money not spent on the project at hand could be used according to a set ratio to increase revenue. In the case of humanitarian relief, each dollar not spent on the relief effort directly could result in an expected benefit for people even if the investment would be independent of the current operational needs. For example, each dollar not spent on transportation costs could be used to improve the quality of the emergency shelters being shipped to the survivors.

This structure is especially helpful when allocating resources over multiple periods with an uncertain horizon.

Principle 2: Aid is given regardless of the race, creed, or nationality of the recipients and without adverse distinction of any kind. Aid priorities are calculated on the basis of need alone. This principle can be broken up into two different constraints. The first portion of the principle discusses bias avoidance in distribution. This is of special concern in last-mile distribution problems when aid is given to an individual. However, it is also important to account for apparent differences in a population at the macro-level. One method of building this constraint into the model is to avoid having anything in the objective function that considers population characteristics beyond quantity/efficacy of aid. Thus, the natural conclusion of the first part of the principle is that the second principle should guide the development of the objective function in a model.

The second portion of the principle would be immediately interesting from a modeling standpoint. If priorities are calculated solely on the basis of need, then it may be appropriate to design models that go beyond protected factors like gender and religion. Calculating aid on the basis of need alone could include things like accessibility, cost, and type of aid. This approach would necessitate the addition of a normalization mechanism that would make aid provision equivalent independent of cost, if all other factors were equal, giving us the first trade-off of the model: number of people assisted vs. assistance equity independent of cost.

Principle 3: Aid will not be used to further a particular political or religious standpoint. To integrate this principle into practice, it is important to focus on maximum coverage, maintaining some equity between different distinct interest groups, while simultaneously ensuring a minimum level of quality. The intentional pursuit of diverse groups is consistent with two of the SFPs (impartiality and neutrality) by ensuring that ease of access is not the sole limiting factor in aid disbursement.

Unfortunately, there are cases where giving aid purely on the basis of need (Principle 2) could serve to further a "political agenda or religious standpoint." In light of Principle 3, we must consider a second trade-off of maximum impact vs. perceived equality. To account for this conflict, it is important to consider local demographics to avoid giving the appearance of bias towards a particular group. This problem will be discussed in greater detail when discussing trade-offs in the model.

Principle 4: We shall endeavor not to act as instruments of government foreign policy. Similar to Principle 3, it may be necessary to require equal distribution across several interest groups even if initial costs or regular costs are greater for some areas due to government opposition. Overall, this principle may be governed more by the areas that an organization chooses to work in, and the projects that they choose to work on, rather than the optimization model itself. The choice of how to avoid being a part of a government foreign policy depends on the type of organization and the particular goal due to the complications of some disaster scenarios (Ebrahim 2003; Hilhorst 2005). The conflict of maximum impact vs. perceived equality will be discussed as a trade-off in the model.

Principle 5: We shall respect culture and custom. Similar to the challenges described in Principles 3 and 4, obeying local customs and culture is complicated and would depend on the projects and partners involved. To incorporate this principle in an optimization model requires that an agency considers "culture and custom" when setting aid objectives. This should also be considered when estimating the cost of assisting an individual after a disaster. The Sphere Handbook (Sphere Project 2011) would be an excellent resource for an agency when selecting the minimum standards for aid, and could also provide context to any regional practices that might alter an aid quantity (e.g., more water in traditionally Muslim communities for ceremonial washing before prayer).

For the model discussed in this paper, we provide a flexible aid structure for a decision maker. Decision makers can select the number of aid levels that they would like to have for each population, and also set the per-person cost for each level of aid. This will be discussed in greater details in the section on model building.

Principle 6: We shall attempt to build disaster response on local capacities. This principle makes it clear that models for aid disbursement should consider the impact on local capacity during the aid process. There are several different methods of constructing a model that account for the impact of an aid effort on local capacity, but unless building on local capacity is the cheapest option for aid, incorporating this principle into the model introduces a new trade-off: short-term aid vs. building on local capacity.

In this paper we incorporate this principle by splitting investment in aid into two categories: aid using outside capacity and aid using local capacity. Any aid performed using the local capacity has an additional impact in the disaster area based on how the trade-off is constructed. In this model we only explore decision making for a single period, so any discount factor for using local resources would be an aggregate of potential future impact. A multi-period model would be significantly more complex in terms of structure and the amount of data required from decision makers to assess the future impact of investment.

Principle 7: Ways shall be found to involve program beneficiaries in the management of relief aid. Similar to Principle 6, from this principle it is also clear that a portion of the objective function should account for investments that leverage local partners and organizations to achieve relief objectives. This paper treats Principles 6 and 7 as having being equivalent for the purpose of big-picture investment. It is difficult to draw further model parameters from this principle since "involve" is such a loose term, and who is involved in the "management of relief aid" is highly situational. It is possible that some level of involvement could be quantified by altering the cost for aid disbursement to account for personal costs (i.e., hiring program beneficiaries to help distribute food). For sub-problems of of aid management this could be a more significant portion of the model, but it would likely need to be tailored to the personal requirements and cultural parameters of the relief situation.

Principle 8: Relief aid must strive to reduce future vulnerability to disaster(s) as well as meeting basic needs. Incorporating this principle into a model requires some creativity. We propose that there are two approaches to building vulnerability reduction into an aid model: (1) Adding a "vulnerability reduction" payoff to each decision alternative as an additional benefit or (2) Having different levels of aid such that basic needs are met before a reduction in vulnerability is achieved for a particular population.

To use the first approach in a model formulation, it would be necessary to develop a stochastic component of the model, or a single expected value, for how each investment might reduce future vulnerability over time. This estimate would likely need to account for risks of future disasters and the mitigative effect of each investment. For example, building permanent structures for housing would be likely to have a higher payoff than setting up tents. However, calculating the difference in impact would be highly dependent on the location of each home, the regional hazards, and the quality of the material used for construction. The "vulnerability reduction" factor would need to be estimated for individual investment options which would increase the amount of information required from the decision maker. In the model proposed for this paper, aid could be broken up into multiple levels with basic needs (e.g., SPHERE levels) as a level, and aid given to reduce vulnerability to future vulnerability could be included as a separate level.

Using different levels of aid would still require that decision makers provide input regarding aid priorities, but would eliminate the need for a "vulnerability reduction" factor. Allowing for multiple levels of aid incorporates Principles 5 and 8 into the model framework by allowing decision makers to have multi-step objectives for different populations while eliminating confusing decision variables and factors.

Principle 9: We hold ourselves accountable to both those we seek to assist and those from whom we accept resources. The two populations discussed in this principle are "those from whom we accept resources" or donors, and "those we seek to assist" or survivors. Navigating the relationships with these two sets of players is an extremely complex and tricky process, and at times the expectations of the two groups may conflict. During the modeling process for a problem, the modeler should attempt to gain a clear understanding of the organization's perceptions of the goals of these two groups, and where they are in conflict, such that a trade-off value can be defined to clarify the contrast between the conflicting goals. In this process, it will also be necessary to clarify what the minimum expectations of each player are and encode these as constraints to the model.

In this model we look at donor and survivor requirements from a monetary perspective since many of the common requirements and challenges appear along this vein. For example, when money is given to an organization involved in humanitarian relief, the donor may identify a specific program or goal for which he/she would like his/her contribution to be used. Similarly, when survivors are promised aid by a relief organization it is important to honor that commitment. In such cases, it is important that the money is used for the requested (committed) aid. From a modeling perspective this can easily be incorporated by adding a constraint for each type of aid and each region. The constraint would ensure that at least the amount of money earmarked by the group of donors (promised to a group of survivors) would be used appropriately.

Key issues in aid distribution to survivors include equity of distribution, as well as the quality and cultural/contextual appropriateness of aid. Distribution of aid in the face of such confounding factors is an especially challenging problem when considering Principles 2, 5, 6, and 8 as previously addressed. Although complicated frameworks could be developed for specific situations, the provision of a general decision making model that is clear, and follows the CoC, is a significant step towards achieving Principle 9.

Principle 10: In our information, publicity and advertising activities, we shall recognize disaster victims as dignified human beings, not hopeless objects. Although Principle 10 primarily focuses on the communication aspects of the aid process, it is also important to recognize that there may be some advantages to exploring how disaster survivors are dignified human beings. To integrate this principle into a decision making model, one aspect of humanity that is considered in this paper is the potential for population mobility and aid diffusion.

While there are situations where a minimum accessibility requirement is needed due to transportation challenges, identifying the correct approach for a disaster situation must account for local ingenuity and creativity. Some examples of survivor creativity include: 1) disaster survivors move towards relief distribution points, 2) individuals that were unaffected by the disaster may still attempt to collect aid, 3) aid recipients may share supplies with family and friends in other areas. All of these cases could result in a lower project efficacy in the population where aid was targeted, but may have a positive effect on other populations in the broader region (especially in cases 1 and 2). In the Discussion section of this paper, we explore how this principle could be incorporated into a future model that accounts for population mobility and aid dispersion.

The breakdown of the individual principles provides an excellent initial framework for our model, but it is still insufficient for effective decision making. In order to build a complete quantitative model it is important to enumerate the underlying trade-offs across the principles.

Trade-off 1: Number of People Assisted vs. Assistance Independent of Cost. Principle 2 clearly indicates the need for equality in aid dispersion, but it is unclear how to reconcile the conflict between cost of aid for an individual and the “humanitarian imperative” coming first (Principle 1). In this model, all expenditures are assumed to have an equal amount of impact However, we allow decision makers some flexibility to prioritize aid by weighting the objective function towards a particular type or level of aid. It is important to note that in this model no sub-population can be explicitly targeted for aid, independent of the type of need. This is to ensure that the model does not allow decision makers to put the humanitarian imperative second to a particular subgroup.

Trade-off 2: Maximum Impact vs. Perceived Equality. The issue of perceived inequality in aid distribution is significant because it can negatively impact an agency’s reputation and ability to operate effectively in an area. In this model, we look at how constraints can be added to an aid model to minimize the disparity in investment. A natural alternative would be to minimize disparity in aid based on the number of people assisted instead of the cost of the assistance.

Trade-off 3: Short-Term Aid vs. Building on Local Capacity. When comparing multiple options for partners or suppliers, the model should involve subsidies to maximize the involvement of program beneficiaries in the relief impact equation. Additionally, the economic impact of investing in the local economy rather than bringing outside personnel can be weighted from literature on economics (Van Hoving et al. 2010).

3.2 Notation

The notation for this model follows directly from the set of principles in the CoC. Where appropriate, the principle(s) that motivated the need for a particular variable will be identified.
Indicies

- i: Indicator for subgroups where there are I subgroups.
- j: Indicator for project type where there are J projects.
- k: Indicator for different levels of aid where there are K levels (Principles 5 and 8).
- l: Indicator for the unique characteristics that a population can have (e.g., religion, political persuasion), where there are L possible characteristics (Principles 2, 3, 4, and 5).

Decision Variables

- $x_{i,j,k}$: Amount spent on subgroup i using external resources for project j to improve to aid level k from $k-1$ (Trade-off 3).
- $y_{i,j,k}$: Amount spent on subgroup i using local resources for project j to improve to aid level k from $k-1$ (Trade-off 3).

Parameters

- A_l: The maximum acceptable disparity in aid between subgroups based on characteristic l (Trade-off 2).
- B: Budget for the region for a particular time frame.
- $\alpha_{i,j,k}$: Difference in impact calculation for use of outside resources ($x_{i,j,k}$) vs. local resources ($y_{i,j,k}$) (Trade-off 3). This is a new area of study in development literature, with early factors and coefficients being developed through the analysis of isolated shock impact on family stability (Hunter et al. 2007).

- $c_{i,j,k}$: Cost of improvement for a person for project j on subgroup i for level k using external resources (Trade-off 3).
- $d_{i,j,k}$: Cost of improvement for a person for project j on subgroup i for level k using local resources (Trade-off 3).
- $h_{i,j,k}$: Initial state of % of needs met for project j, subgroup i, and aid level k at the start of the optimization calculation.
- $m_{i,j}$: Money donated for, or committed to, a subgroup i for project j (Principle 9).
- p_i: Population of subgroup i.
- $q_{i,j,k}$: Quality factor for project, or the credit valuation of the project based on the minimum cost between $c_{i,j,k}$ and $d_{i,j,k}$. Different agencies have different weights for desired benefit in a particular area, the quality factor $q_{i,j,k}$ is introduced to normalize the cost component.
- $r_{i,l}$: Value for each unique characteristic l of each subgroup i (Principles 2, 3, and 4). It is mentioned in Principles 2, 3, and 4 that the aid should be independent of any discrimination based on politics, religion, race, gender, etc. The characteristics is considered with binary values where there are two types of a specific characteristic (0 and 1) and the characteristic of each subgroup is known ($r_{i,l}$).
- $w_{j,k}$: Payoff benefit per person, per dollar for a specific project type j from level $k-1$ to level k (Trade-off 1).

3.3 Assumptions

In this section, we enumerate the assumptions involved in this model. As much as possible, the model proposed in this paper is targeted towards practical application in the relief context, but it is not possible to develop a completely comprehensive model.

Assumption 1 Homogeneous Subgroups. We assume that each region can be split up into an arbitrary number of subgroups which are internally homogeneous (e.g., all members of a subgroup have the same religion). These subgroups would not need to be identically sized since the proposed model accounts for specific populations.

Assumption 2 Unbiased Towards Cheap Project. We assume that an equal amount of money spent towards one project vs. another more expensive project would have equal value in the objective function if the two weights were also equal.

Assumption 3 Single Time Period. The decision model presented here is designed to provide a decision maker with a mechanism for ongoing decisions, but does not attempt to incorporate multi-period planning, although this would be an interesting extension to the model.

Assumption 4 Aid Should only be Targeted to a Need. In this model, we only allow a decision maker to set preferences for aid towards a particular project or level, but not towards a subgroup.

Assumption 5 Unlimited Resources for Purchase. To limit the scope of the paper, the current formulation is set up for the scenario where there is unlimited resources with steady cost. Future work will explore the incorporation of a supply and demand model where there is a limit to the resources available externally and internally, and dynamic costs as the amount of resources purchased changes.

4 Model building

In this section we build the proposed model and reference the principles that provide the motivation for each component. The formulation is fairly standard such that new constraints or a new objective function could be added.

Objective function The objective function (Z) in our formulation is primarily motivated by Principle 1 (humanitarian imperative first). It should be noted that the objective function maximizes aid impact according to an organization-specific weighting scheme ($w_{j,k}$), and is not a cost minimization objective.

$$\max_{x_{i,j,k}, y_{i,j,k} \forall i \in I, j \in J, k \in K} Z = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left(w_{j,k} q_{i,j,k} \left(\frac{x_{i,j,k}}{c_{i,j,k}} + \frac{y_{i,j,k} \left(1 + \alpha_{i,j,k}\right)}{d_{i,j,k}} \right) \right)$$

By breaking up the different components of aid in the objective function, we allow an agency to target aid within a specific category to use Principle 2 when planning a relief effort (calculating aid priorities on the basis on need alone). Additionally, by allowing the agency to target aid at a level that meets local needs and priorities, the objective function makes it possible for target aid using Principle 5 (respecting culture and custom). Finally, having a model that breaks down and weights the reasoning for investing in different subgroups and projects will help to provide a clear defense for how agencies spend resources, allowing an agency to be accountable to recipients of aid as well as supporters (Principle 9). The objective function should be scalable such that an agency could choose to have as many levels of aid (K) as appropriate for the aid context.

In the objective function presented here, we only attempt to maximize the dollar impact felt by the targeted populations. This can be seen by the fact that the costs of aid ($c_{i,j,k}$ and $d_{i,j,k}$) for a specific region are explicitly incorporated into the objective function. There would be no benefit in just doing cheaper projects (e.g. food instead of medical care) unless it was clear that one was a higher priority as weighted ($w_{i,j,k}$) by the decision maker using a normalized weighting scheme (i.e., $\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left(w_{i,j,k}\right) = 1$).

An important nuance of the objective function is that local and external aid efficacy may be weighted differently depending on the value of $\alpha_{i,j,k}$ and which delivery method is cheapest. Specifically, we must introduce the first two constraints to allow for correct accounting of project value in an unbiased manner. Many impact equations tend to ignore a normalization factor for cost, resulting in the cheapest projects being the ones implemented in a disaster environment since there appears to be the biggest bang for the buck. However, it is important to recognize that different agencies have different weights for desired benefit in a particular area, and so we intentionally normalize the cost component using a quality factor $q_{i,j,k}$, making it the minimum cost to provide a particular service in an area.

$$q_{i,j,k} - c_{i,j,k} \leq 0, \quad \forall i \in I, j \in J, k \in K. \tag{1}$$

$$q_{i,j,k} - d_{i,j,k} \leq 0, \quad \forall i \in I, j \in J, k \in K. \tag{2}$$

Levels of Aid Here we introduce the core constraints for the model. This set of constraints limits how much aid can be given directly to a sub-group at each level of need (k) where there are K levels to meet the specific objectives of a decision maker. The constraints ensure that the percentage improvement in aid type j for subgroup i at level k has already been achieved at a lower/prerequisite level. For example, it may be important to provide pots and pans to disaster survivors before dry rice so that the recipients can cook the food. This is especially important for agencies attempting to achieve a specific level of aid or donor objective in a sustainable way. If the aid levels were not separated, the problem formulation would be simpler but would fail to address Principles 2, 5, and 8.

The introduction of Constraint 4 provides a bound to the benefit that can be claimed for achieving a certain level of aid in a region. While additional investments can provide benefit, the provision of basic humanitarian aid is the primary goal with a k level. Once 100% of the k level is reached (e.g., quarter SPHERE food level reached) then any additional food would go towards the half SPHERE level ($k+1$) and should be counted using that impact factor, essentially forcing the optimization algorithm to follow the law of diminishing returns. Given that the number of levels K can be high, there is not a constraint on the amount of resources that can be given to a region, but there is a controlled rate of return that can be claimed in terms of local impact.

$$\frac{x_{i,j,k}}{p_i c_{i,j,k}} + \frac{y_{i,j,k}}{p_i d_{i,j,k}} - \left(\frac{x_{i,j,k-1}}{p_i c_{i,j,k-1}} + \frac{y_{i,j,k-1}}{p_i d_{i,j,k-1}} + h_{i,j,k-1}\right) \leq 0, \quad \forall i \in I, j \in J, k \in K. \tag{3}$$

$$\frac{x_{i,j,k-1}}{p_i c_{i,j,k-1}} + \frac{y_{i,j,k-1}}{p_i d_{i,j,k-1}} + h_{i,j,k-1} - 1 \leq 0, \quad \forall i \in I, j \in J, k \in K. \tag{4}$$

Budgets While the overall effort is driven by meeting the needs of individuals affected by the disaster, it is important to incorporate an explicit set of budgetary constraints to ensure that the amount of resources spent in a period is within the organizational budget and commitments. In the proposed model, we use a general budget amount (B) for the primary constraint, and then add specific constraints for donor-requested/promised projects. The primary budget constraint is to ensure that all aid dispersement does not exceed the amount allocated for the relief effort.

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}\left(x_{i,j,k} + y_{i,j,k}\right) - B \leq 0 \tag{5}$$

The next three constraints are specific to donor requirements for how money will be spent. Most models will only use a subset of these equations, but all of the possible equations are enumerated for the sake of completeness. If the amount donated for a specific goal is 0, then the set of equations reduce to the trivial constraint $x_{i,j,k} + y_{i,j,k} \geq 0$.

This constraint ensures that the amount spent in subgroup i on project j exceeds the amount donated for that specific purpose.

$$m_{i,j} - \sum_{k=1}^{K}\left(x_{i,j,k} + y_{i,j,k}\right) \leq 0, \quad \forall i \in I, j \in J. \tag{6}$$

This next budget constraint ensures that the amount spent on project j exceeds the amount donated for that specific purpose.

$$o_j - \sum_{i=1}^{I}\sum_{k=1}^{K}\left(x_{i,j,k} + y_{i,j,k}\right) \leq 0, \quad \forall j \in J. \tag{7}$$

This final budget constraint ensures that the amount spent in subgroup i exceeds the amount donated for that subgroup. This can also be generalized to a set of i's with some common characteristic (e.g., homeless survivors) where $i \in i'$ by adding an additional summation $\sum_{i}^{i'}$.

$$n_i - \sum_{j=1}^{J} \sum_{k=1}^{K} \left(x_{i,j,k} + y_{i,j,k}\right) \leq 0, \quad \forall i \in I. \tag{8}$$

Minimizing Disparity in Aid One key component of aid that is mentioned in Principles 2, 3, and 4 is to have aid be independent of any discrimination based on politics, religion, race, gender, etc. To achieve this goal we propose a general formulation which would provide a maximum acceptable level of disparity between different groups. In our basic formulation we only explore characteristics with binary values where there are two types of a specific characteristic (0 and 1) and the characteristic of each subgroup is known ($r_{i,l}$). The number of binary characteristics is unlimited, and if a more complex relationship is required, this could be achieved as a series of binary relationships between groups. To provide a bi-directional limit on the range of investments that are acceptable, we present the limitation as a pair of equations for each characteristic. This approach allows for a wide array of characteristics to be considered without increasing the dimensionality of the problem. Constraints 9 and 10 are repeated for all pairs of $i \in I$ to minimize inequality between population subgroups.

$$\sum_{i=i^1,i^2}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left(r_{i^1,l} - r_{i^2,l}\right) \left(x_{i,j,k} + y_{i,j,k}\right) - A_l \leq 0, \quad \forall \quad pairs \quad i^1, i^2 \in I. \tag{9}$$

$$\sum_{i=i^1,i^2}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \left(r_{i^2,l} - r_{i^1,l}\right) \left(x_{i,j,k} + y_{i,j,k}\right) - A_l \leq 0, \quad \forall \quad pairs \quad i^1, i^2 \in I. \tag{10}$$

5 Example application

In this section, we walk through a practical example to better explore the concepts discussed and the model proposed in this paper. To make the methodology accessible to decision makers and organizations in the disaster relief context, this example was developed using Excel 2010 and solved with a plug-in from CoinOR called OpenSolver. The focus of this example is the provision of aid to refugee camps in Turkey that have sprung up after the beginning of the Syrian civil war in 2011 which was exacerbated by the rise of the Islamic State in Syria and Iraq. One of the challenges of long-term relief work in refugee camps is that there can be a competing agenda between development and humanitarian aid, ironically a contrast that was initially explored in work around refugees from Pakistan living in Syria (Gabiam 2012). The model proposed in this paper provides a multi-tiered system for each type of aid, allowing a transition from aid to development, although the direct analysis of this transition is outside the scope of this work.

5.1 Model description

Let us assume that we are assisting the World Food Program (WFP) managing a significant portion of the food distribution between refugee camps in Turkey, helping provide daily food aid to roughly 250,000 people a day in 2016 (PBS 2016). While there were over 2 million other refugees in Turkey, the structure of aid in Turkey by the WFP is such that aid is targeted to those in 22 managed camps as shown on the map in Fig. 1 (Fanack 2016). The target population in Turkey can be broken up as shown in Table 1, with no additional weights or differences between the camps where the individuals are staying since the WFP deals with countries as a while to minimize competition and internal strife.

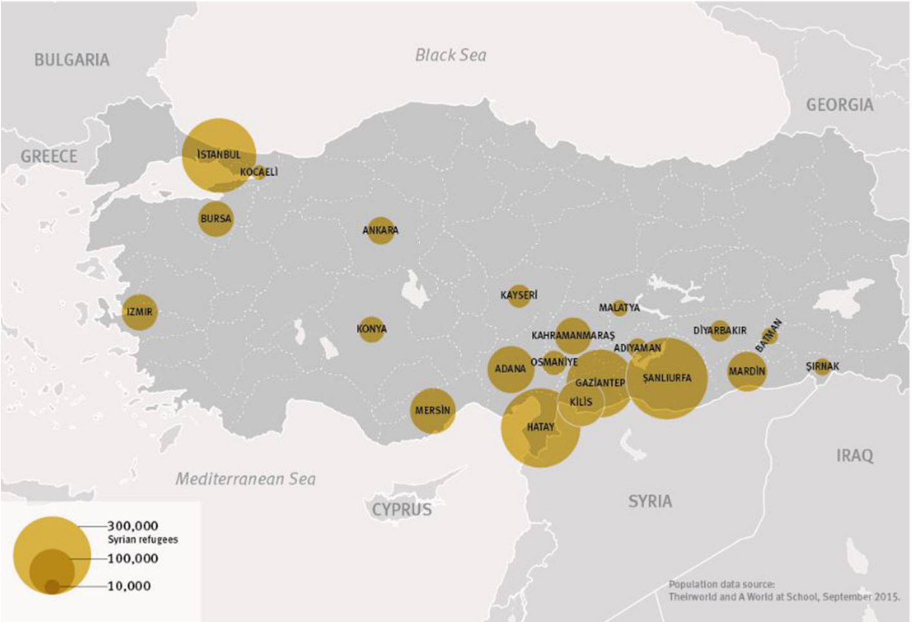

Fig. 1 As of 2016, there were 22 official Syrian refugee camps in Turkey along the Syria–Turkey border, with a complex, multi-front conflict ongoing in Syria (Fanack 2016)

Table 1 General subgroup information

Subgroup	Method		
	Subgroup name	Population size	Primary political affiliation
1	Arrived after March 2016 Kurds	20,000	Kurds
2	Arrived after March 2016 Arabs	40,000	Arabs
3	Arrived before March 2016 Kurds	100,000	Kurds
4	Arrived before March 2016 Arabs	90,000	Arab

To develop a profile of each subgroup, we provide a set of general information categories for WFP to fill out. For this example, we focus on analyzing the historical ethnicity of the subgroups to ensure that aid disbursement is perceived as being neutral

A significant component of the challenge to aid distribution in Turkey was that some of the refugees are Kurdish, a minority population in Turkey and there is a history of political tension in the region (Gunter 2015). There is a mixture of tension between Arabs, Kurds, and Turks that impacts which camps refugees are willing to stay in, the perceived equality between camp conditions, and even personal security (Mortimer 2015). Consistent funding issues and gaps due to the ongoing nature of the crisis resulted in WFP cutting food aid to a third of Syrian refugees in 2015, making it critical to have a guiding model for aid prioritization in particularly volatile regions like Turkey The Guardian (2015). This dynamic was complicated by a March 2016 deal between Turkey and the European Union (EU) for migrants to Europe to be returned to Turkey, and some of the migrants that were already in Turkey to be settled in Europe (Collett 2016). While there is some mixing of individuals at each camp, for this problem we will treat each group as if they were housed at different camps.

Table 2 Cost estimates for each subgroup

Aid level	$13.50/person/month		$27/person/month	
Subgroup	Method			
	External	Local	External	Local
1	$20.00	$30.00	$30.00	$40.00
2	$10.00	$20.00	$15.00	$40.00
3	$50.00	$60.00	$50.00	$100.00
4	$50.00	$60.00	$50.00	$100.00

WFP has estimated the cost of providing food to each person in the camps for a month at two different levels of aid using external versus local resources

Table 3 Sharing percentages between groups

From subgroup	To sugroup			
	1 (%)	2 (%)	3 (%)	4 (%)
1	0	10	0	0
2	10	0	0	0
3	15	5	0	0
4	5	20	0	0

WFP has estimated that aid given to each groups can move across group and camps lines as shown in the percentage breakdown

Despite the long-term nature of the scenario, due to low budgets and fluctuating numbers of immigrants, WFP has had to constantly assess where aid was most desperately needed. The primary method of food distribution used in the Turkish refugee camps is food vouchers with dollar values that can be used to purchase food. In the current example, we look at two different voucher levels (WFP 2015), which are US Dollar $13.50/person/month and $27/person/month.

In our scenario, we use hypothetical money values in this example application. We assume the WFP received $8,000,000 ($B$) to assist in the disaster relief effort over the next month, and at least $1,000,000 must be used to for recent refugees that have arrived since March of 2016 when the resettlement deal began due to restrictions by the EU regarding the funds provided (Collett 2016). Additionally, due to increasingly polarized politics in the region after a failed coup in July of 2016, it is important that there is a limited disparity in the amount of aid that the two groups receive (for this example, $100,000) to ensure that the WFP is not accused of being biased towards people of Kurdish or Arab decent (Sara 2016).

Since aid can be purchased and transported using external resources ($x_{i,j,k}$) or local resources ($y_{i,j,k}$), WFP has estimated the cost of providing food per person for each subgroup as shown in Table 2 which also accounts for program administration costs at the different camps, transport costs of delivering food to the camp stores, and security for the aid workers and distribution sites. However, as noted in the section on model formulation, it is important to examine the ratio of $\frac{c_{i,j,k}(1+\alpha_{i,j,k})}{d_{i,j,k}}$ when assessing whether to use local or external resources to provide aid.

One of the interesting dynamics that occurs in relief environments where there is a high level of cultural affinity or disaffinity is that aid given to one group can be transferred to other communities in the region through familial ties or alliances. In the case of Syrian refugees, we look at the transfer of resources from one group to another within the groups of similar ethnicity, with some example transfer percentages shown in Table 3. Here we assume that the more established group (groups 3 and 4) will share sources with new arrivals, and that the new arrivals are willing to share with one another.

WFP has prioritized aid using the following weight vector $\boldsymbol{W}_{j=1,k\in K} = (2/3, 1/3)$ such that helping survivors get to the $13.50 level is twice as important as getting individuals to the

\$27 level. As mentioned previously, the efficacy between using local and external resources is typically calculated or estimated by experts in the domain based on prior work, although there is some early analysis of how this trade-off could be calculated in practice. For this example, we set values of α that would be generated by experts that had been working in refugee work in the area for many years, accounting for impacts such as disease incidence, crime frequency, and local inflation rate. Here we assume that WFP found from previous work in the region that using external resources to provide aid is the most effective at the most basic level (in this case, \$13.50/person/month), and then $\alpha_{i,j,k}$ increases for later levels of aid. For our calculation, we let $\alpha_{i,1,1} = 0$ (no additional benefit for using local resources and personnel to reach \$13.50/person/month). This would be primarily due to the loss of extra food and potential corruption due to the low aid levels. However, the $\alpha_{i,1,2} = 0.5$ (50% improvement in long-term impact using local resources to get to \$27/person/month) for all subgroups in the impacted region due to an increased benefit of employing local individuals and seeing new businesses built around the refugee camps.

5.2 Results

Using the model framework proposed in this paper, The impact of the decision structure for this example is presented in Table 4. "No WFP" column represents initial situation and "With WFP" column after model is implemented. This is typical of response or aid environments where there is a shortage of resources below the desired and targeted level; this dynamic tends to increase use of external management to decrease fraud and theft. Additionally, it should be noted that to get individuals to the \$27 level, it was recommended that the emphasis be shifted to use of local resources in for camps where any community was. This is also very typical of aid environments to improve the long-term impact of aid and stability of the community. The optimal resource allocation is shown in Table 5. It is important to notice in Table 5 that the external resources were used disproportionately for managing the initial distribution program. In this particular example, this was a direct result of the ratio $\frac{c_{i,j,k}(1+\alpha_{i,j,k})}{d_{i,j,k}}$. Because the ratio is greater than 1 for all the camps dominated by these subgroups, only local channels were used to provide aid acquisition and disbursement to the community.

It is important to discuss the investment dynamics that resulted in the significantly higher cost for the groups that has been in Turkey longer, than for subgroup 1 (in particular). This is primarily a result of the similar amount of impact that helping an individual from any group to the second tier of aid (\$27 in this case) combined with the benefit of stability that resulted in decreased costs for a higher level of investment. The intent here is not to show that aid should be given to groups that arrived more recently, rather than it is more expensive

Table 4 Optimal resource allocation scheme

Aid level	\$13.50/person/month		\$27/person/month	
Subgroup	Pop %			
	No WFP (%)	With WFP (%)	No WFP (%)	With WFP (%)
1	20	100	5	24
2	10	100	2	2
3	50	100	20	100
4	50	100	20	99

Using the proposed framework, the budget will be allocated to the following subgroup' camps for aid

Table 5 Optimal resource allocation scheme

Using the proposed framework, the available budget was split between the 4 different subgroups using local and external resources

Aid level	$13.50/person/month		$27/person/month	
Subgroup	Method			
	External	Local	External	Local
1	$480,000	$ –	$ –	$150,000
2	$1,080,000	$ –	$ –	$ –
3	$1,000,000	$ –	$ –	$ 2,320,000
4	$900,000	$ –	$ –	$ 2,070,000

to provide aid to groups that do not have a stable infrastructure and community organization for managing the distribution of such aid. This is a constant challenge in aid environments and is where there is an explicit variable for managing the imbalance of investment between groups (Kurds and Arabs) and a minimum investment amount of new arrivals. To correctly implement this approach in an aid environment, it would be important to identify the type and range of each budget and disparity constraint to ensure that the organization is achieving mandate in the target community.

5.3 Sensitivity analysis for the relief optimization model

One of the challenges of assessing the potential impact of a new model in a complex environment is understanding how resilient the model will be to changing dynamics and variables. For this paper we will focus on a subset of the variables pertinent to the problem, leaving the number of population characteristics, sub-populations, aid types, and aid tiers constant to simplify our analysis. For the approach, we used a 2^k fractional factorial level III design with the FrF2 package in *R*. In this sensitivity analysis we looked at 12 different variables including how different population mixes, budgets, minimum spending requirements, sub-population affiliations, aid prioritizations, previous aid levels, and aid costs from each source. Results were compared based on the overall objective function value and the number of people assisted at each level of aid from each subgroup. Here we enumerate the key results from the initial sensitivity analysis results.

- Increased Aid Budgets resulted in better outcomes across the board, but there is a marginal rate of return on budget increases especially when more basic levels have higher weightings.
- Providing Aid to a Region with a Clear Minority and Majority was significantly less efficient across the board. This is critical to note when assessing strategy for providing aid to regions where there are significant cultural divisions within the refugee or IDP population.
- Prioritization of Aid Levels helps to improve aid performance as measured by the objective function, but does not translate into a marked improvement in the population?s ultimate state and receipt of aid. This is important to recognize that where there are minimum levels of aid needed, having organization aid priorities is fine for internal metrics but does not translate into an improved population state in the long-term.
- Previous Aid Levels do not adversely impact the objective function of the organization when it is constructed in a balanced manner as proposed by this paper.
- Use of Local Aid Resources is always beneficial when using this model approach because any additional increase in cost is offset by the valuation of using local partners and resources. However, this information is critical in conjunction with the final trend.

- Using Explicit Impact Multipliers for purchasing aid supplies from local sources provides a significant increase in the objective function (perceived organizational efficacy) but results in less direct impact and aid for the targeted populations, specifically because it costs more to have people get aid at lower levels, and so significantly fewer people can get aid at the higher levels.

These initial results provide a grounding for how and when a model like the one proposed should be used in practice. While a significant number of questions and challenges remain in providing equitable aid, we believe this model will help to advance the discussion of how appropriate protocol and methodology should be reflected in the development of models and tactical protocol for aid distribution.

6 Future research directions and conclusion

6.1 Future research directions

The model proposed in this paper is designed to provide a basic model for disaster researchers that is built on the qualitative principles of the disaster relief community. However, there are certainly other approaches or modifications that could be done using the IFRC's CoC, and in this section we provide a brief discussion of some other things that could be considered when modeling the problem of aid allocation.

Multiple regions In this model we look at a specific region where a relief agency has been engaged or intends to engage. This region is then split into subgroups with costs for meeting the specific needs of each subgroup. A natural extension of this model is to consider expanding it to multiple regions with some fixed cost for entering the region (an "activation" cost to gain access to a region). This would be another dimension to the model (i, j, k instead of i, j where k is the region). In the core model presented here we do not explore this because it increases the model size and we wanted to focus on the core.

However, if an agency is considering working across multiple regions where there is a fixed cost associated with entering each new region, it may be important to use an expanded model unless: 1) the budget is allocated to different regions independent of modeled impacts, then a subgroup model could be used in reach region independently, 2) the cost to access different regions is negligible and multiple regions can be included in a larger subgroup model, or 3) the cost of accessing different regions can be included into the project specific costs for reaching out to a subgroup for a particular project, in which case a larger subgroup model could still be used.

Multi-period decision models The model presented here only looks at the case for a one-shot decision. This is reasonable for some disaster contexts where the aid situation is assessed and the response process is immediate; incorporating an estimate of the future state of the disaster survivors would make it much more difficult to gather the information necessary to make a useful recommendation. Although the principles presented translate well into a multi-dimensional space, the addition of multiple periods adds a significant degree of complexity to the model, and is saved for future work.

Population interaction and movement Principle 10 encourages relief agencies to consider disaster victims as "dignified human beings, not hopeless objects." To this end, in an expanded formulation of the model we could add a "dispersion" component where disparity in investment between subgroups will result in aid being dispersed to the other subgroups through non-official channels. This consideration of interaction and resource flow would significantly increase the complexity of the model.

6.2 Conclusion

Providing effective and equitable aid after a disaster is an essential task for large relief organizations like the Red Cross. Since the field of disaster management is so decentralized, it is important to identify a set of standards that can provide a baseline for what it means to provide effective aid in a wide array of scenarios. The Red Cross and Red Crescent Society's Code of Conduct (CoC) for Disaster Operations provides just that. This qualitative set of guidelines is an excellent building block for operational theory, but is insufficiently rigorous to guide practical decision making without effective quantitative models.

In this paper we reviewed the CoC, exploring each of the 10 core principles and identifying 3 significant operational trade-offs. We then proposed a framework that can be implemented as a standalone model, or can be used as a foundation for other quantitative aid allocation models. Finally, we provided an example of how the proposed model could be used to guide decision making in a Microsoft Excel ® environment using CoinOR's OpenSolver ®.

References

Altay, N., & Green, W. G. (2006). OR/MS research in disaster operations management. *European Journal of Operational Research*, *175*(1), 475–493.

Andre, G., & Collins, S. (2001). Raising standards in emergency relief: How useful are sphere minimum standards for humanitarian assistance? *British Medical Journal*, *323*(7315), 740–742.

Balcik, B., & Beamon, B. M. (2008). Facility location in humanitarian relief. *International Journal of Logistics*, *11*(2), 101–121.

Balcik, B., Beamon, B. M., & Smilowitz, K. (2008). Last mile distribution in humanitarian relief. *Journal of Intelligent Transportation Systems*, *12*(2), 51–63.

Barbaroso, G., & Arda, Y. (2004). A two-stage stochastic programming framework for transportation planning in disaster response. *Journal of the Operational Research Society*, *55*(1), 43–53.

Barbarosoğlu, G., Özdamar, L., & Cevik, A. (2002). An interactive approach for hierarchical analysis of helicopter logistics in disaster relief operations. *European Journal of Operational Research*, *140*(1), 118–133.

Beamon, B. M., & Balcik, B. (2008). Performance measurement in humanitarian relief chains. *International Journal of Public Sector Management*, *21*(1), 4–25.

Beamon, B. M., & Kotleba, S. A. (2006). Inventory modelling for complex emergencies in humanitarian relief operations. *International Journal of Logistics: Research and Applications*, *9*(1), 1–18.

Birkmann, J. (2006). *Measuring vulnerability to natural hazards: Towards disaster resilient societies*. Tokyo: United Nations University Press.

Bryant, C., & Lindenberg, M. (2001). *Going global: Transforming relief and development NGOs*. Yorktown Heights, NY: Kumarian Press.

Clay Whybark, D. (2007). Issues in managing disaster relief inventories. *International Journal of Production Economics*, *108*(1), 228–235.

Collett, E. (2016). The paradox of the eu-turkey refugee deal. http://www.migrationpolicy.org/news/paradox-eu-turkey-refugee-deal. Accessed March 2017.

Currion, P., Silva, C., & van de Walle, B. (2007). Open source software for disaster management. *Communications of the ACM*, *50*(3), 61–65.

De Angelis, V., Mecoli, M., Nikoi, C., & Storchi, G. (2007). Multiperiod integrated routing and scheduling of world food programme cargo planes in angola. *Computers & Operations Research*, *34*(6), 1601–1615.

Ebrahim, A. (2003). Accountability in practice: Mechanisms for ngos. *World Development*, *31*(5), 813–829.

Eckhart, J., Allen, J., & Tuomala, J. (2013). Stop starving scale: Unlocking the potential of global ngos. http://www.bridgespan.org/getmedia/ca2c40f0-5a70-475f-9e6c-90682b178bc5/StopStarvingScale-UnlockingthePotentialofGlobalNGOs.pdf.aspx. Accessed March 2017.

Esty, D. C. (1998). Non-governmental organizations at the world trade organization: Cooperation, competition, or exclusion. *Journal of International Economics Law*, *1*(1), 123–147.

Fanack (2016). Syrian refugees increasingly used as bargaining chips. https://chronicle.fanack.com/turkey/history-past-to-present/turkey-coping-with-refugees/. Accessed March 2017.

Gabiam, N. (2012). When humanitarianism becomes development: The politics of international aid in syria's palestinian refugee camps. *American Anthropologist*, *114*(1), 95–107.
Gao, H., Barbier, G., & Goolsby, R. (2011). Harnessing the crowdsourcing power of social media for disaster relief. *IEEE Intelligent Systems*, *26*(3), 10–14.
Guay, T., Doh, J. P., & Sinclair, G. (2004). Non-governmental organizations, shareholder activism, and socially responsible investments: Ethical, strategic, and governance implications. *Journal of Business Ethics*, *52*(1), 125–139.
Gunter, M. M. (2015). Iraq, Syria, Isis and the Kurds: Geostrategic concerns for the U.S. and Turkey. *Midle East Policy*, *22*(1), 102–111.
Hausken, K., & Zhuang, J. (2016). The strategic interaction between a company and the government surrounding disasters. *Annals of Operations Research*, *237*(1), 27–40.
Hilhorst, D. (2005). Dead letter or living document? ten years of the code of conduct for disaster relief. *Disasters*, *29*(4), 351–369.
Hulkower, R. (2010). The history of the hippocratic oath: Outdated, inauthentic, and yet still relevant. *The Einstein Journal of Biology and Medicine*, *25/26*(1), 1–46.
Hunter, L. M., Twine, W., & Patterson, L. (2007). "locusts are now our beef": Adult mortality and household dietary use of local environmental resources in rural south africa. *Scandinavian Journal of Public Health*, *35*(69), 165–174.
Kent, R. C. (1987). *Anatomy of disaster relief: The international network in action*. London, England: Pinter Publishers.
Khan, M. M., & Ahmed, S. (2003). Relative efficiency of government and non-government organisations in implementing a nutrition intervention programme—a case study from Bangladesh. *Public Health Nutrition*, *6*(01), 19–24.
Kovacs, G., & Spens, K. M. (2011). Trends and developments in humanitarian logistics—a gap analysis. *International Journal of Physical Distribution & Logistics Management*, *41*(1), 32–45.
Lee, H. L. (2000). Creating value through supply chain integration. *Supply Chain Management Review*, *4*(4), 30–36.
Lowell, S., Trelstad, B., & Meehan, B. (2005). The ratings game: Evaluating the three groups that rate the charities. *Stanford Social Innovation Review*, *3*(2), 38–45.
Mete, H. O., & Zabinsky, Z. B. (2010). Stochastic optimization of medical supply location and distribution in disaster management. *International Journal of Production Economics*, *126*(1), 76–84.
Moore, S., Eng, E., & Daniel, M. (2003). International NGOs and the role of network centrality in humanitarian aid operations: A case study of coordination during the 2000 mozambique floods. *Disasters*, *27*(4), 305–318.
Mortimer, J. (2015). Kurdish refugees reject government-run camp in Turkey. http://www.al-monitor.com/pulse/originals/2015/03/turkey-kobane-kurdish-refugees.html. Accessed March 2017.
National Society of Professional Engineers (2007). NSPE code of ethics for engineers. http://www.nspe.org/resources/ethics/code-ethics. Accessed March 2017.
PBS (2016). Inside the harsh living conditions for Syrian refugees in Turkey. http://www.pbs.org/newshour/bb/inside-the-harsh-living-conditions-for-syrian-refugees-in-turkey/. Accessed March 2017.
Rawls, C. G., & Turnquist, M. A. (2010). Pre-positioning of emergency supplies for disaster response. *Transportation Research Part B: Methodological*, *44*(4), 521–534.
Red Cross Federation, I. (1965). The seven fundamental principles. http://www.ifrc.org/vision-et-mission/vision-et-mission/les-7-principes-les-7-principes/. Accessed March 2017.
Red Cross Federation, I. (1994). Code of conduct. http://www.ifrc.org/en/publications-and-reports/code-of-conduct/. Accessed March 2017.
Sara, S. (2016). Turkey gripped by fear in aftermath of failed coup. http://www.abc.net.au/news/2016-10-04/turkey-gripped-by-fear-in-aftermath-of-failed-coup/7894250. Accessed March 2017.
Sbayti, H., & Mahmassani, H. S. (2006). Optimal scheduling of evacuation operations. *Transportation Research Record: Journal of the Transportation Research Board*, *1964*(1), 238–246.
Seaman, J. (1999). Malnutrition in emergencies: How can we do better and where do the responsibilities lie? *Disasters*, *23*(4), 306–315.
Shapiro, M. (1997). The problems of independent agencies in the United States and the European Union. *Journal of European Public Policy*, *4*(2), 276–277.
Simatupang, T. M., Wright, A. C., & Sridharan, R. (2002). The knowledge of coordination for supply chain integration. *Business Process Management Journal*, *8*(3), 289–308.
Smilowitz, K. R., & Dolinskaya, I. (2011). *Decision-making tools for distribution networks in disaster relief*, McCormick, Northwestern Engineering, Center for the Commercialization of Innovative Transportation Technologies.

Sperling, L. (2002). Emergency seed aid in Kenya: Some case study insights on lessons learned during the 1990s. *Disasters*, *26*(4), 329–342.

Sphere Project (2011). Sphere handbook: Humanitarian charter and minimum standards in disaster response. http://www.refworld.org/docid/4ed8ae592.htm. Accessed March 2017.

Stephenson, M, Jr. (2005). Making humanitarian relief networks more effective: Operational coordination, trust and sense making. *Disasters*, *29*(4), 337–350.

Stephenson, M, Jr., & Schnitzer, M. (2006). Interorganizational trust, boundary spanning, and humanitarian relief coordination. *Nonprofit Management and Leadership*, *17*(2), 211–233.

Sutton, J., Palen, L., & Shklovski, I. (2008). Backchannels on the front lines: Emergent uses of social media in the 2007 southern california wildfires. In *Proceedings of the 5th international ISCRAM conference*, Washington, DC, pp. 624–632.

The Guardian (2015). Lack of funds: World food programme drops aid to one-third of syrian refugees. https://www.theguardian.com/world/2015/sep/05/lack-of-funds-world-food-programme-drops-aid-to-one-third-of-syrian-refugees. Accessed March 2017.

Tzeng, G. H., Cheng, H. J., & Huang, T. D. (2007). Multi-objective optimal planning for designing relief delivery systems. *Transportation Research Part E: Logistics and Transportation Review*, *43*(6), 673–686.

Van Hoving, D. J., Wallis, L. A., Docrat, F., & De Vries, S. (2010). Haiti disaster tourisma medical shame. *Prehospital & Disaster Medicine*, *25*(3), 201–202.

Vitoriano, B., Ortuño, M. T., Tirado, G., & Montero, J. (2011). A multi-criteria optimization model for humanitarian aid distribution. *Journal of Global Optimization*, *51*(2), 189–208.

Vitoriano, B., Ortuno, T., & Tirado, G. (2009). Hads, a goal programming-based humanitarian aid distribution system. *Journal of Multi-Criteria Decision Analysis*, *16*(1–2), 55–64.

WFP (2015). WFP forced to make deeper cuts in food assistance for Syrian refugees due to lack of funding. https://www.wfp.org/news/news-release/wfp-forced-make-deeper-cuts-food-assistance-syrian-refugees-due-lack-funding. Accessed March 2017.

Xiang, Y., & Zhuang, J. (2016). Medical resource allocation serving disaster victims with deteriorating health conditions. *Annals of Operations Research*, *236*(1), 177–196.

Xu, J., & Zhuang, J. (2016). Modeling costly learning and counter-learning in a defender-attacker game with private defender information. *Annals of Operations Research*, *236*(1), 271–289.

Xu, J., Zhuang, J., & Liu, Z. (2016). Modeling and mitigating the effects of supply chain disruption in a defender-attacker game. *Annals of Operations Research*, *236*(1), 255–270.

Xu, L., & Beamon, B. (2006). Supply chain coordination and cooperation mechanisms: An attribute-based approach. *Journal of Supply Chain Management*, *42*(1), 4–12.

Yan, S., & Shih, Y. (2009). Optimal scheduling of emergency roadway repair and subsequent relief distribution. *Computers & Operations Research*, *36*(6), 2049–2065.

Yates, D., & Paquette, S. (2011). Emergency knowledge management and social media technologies: A case study of the 2010 Haitian earthquake. *International Journal of Information Management*, *31*(1), 6–13.

Yi, W., & Özdamar, L. (2007). A dynamic logistics coordination model for evacuation and support in disaster response activities. *European Journal of Operational Research*, *179*(3), 1177–1193.

Zhuang, J., Saxton, G., & Wu, H. (2014). Publicity vs. impact in nonprofit disclosures and donor preferences: A sequential game with one nonprofit organization and n donors. *Annals of Operations Research*, *221*(1), 469–491.