RELIEF DISTRIBUTION NETWORKS: A SYSTEMATIC REVIEW

A.M. Anaya-Arenas, J. Renaud, A. Ruiz

Centre interuniversitaire de recherche sur les réseaux d'entreprise, la logistique et le transport (CIRRELT), Université Laval, Quebec, Canada, G1V 0A6

and

Département opérations et systèmes de décision, Faculté des sciences de l'administration, Pavillon Palasis-Prince, Université Laval, 2325, rue de la Terrasse, Quebec, Canada, G1V 0A6

anamaria.anayaarenas@cirrelt.ca; jacques.renaud@fsa.ulaval.ca; angel.ruiz@fsa.ulaval.ca

Abstract

In the last 20 years, Emergency Management has received increasing attention from the scientific community. Meanwhile, the study of relief distribution networks has become one of the most popular topics within the Emergency Management field. In fact, the number and variety of contributions devoted to the design or the management of relief distribution networks has exploded in the recent years, motivating the need for a structured and systematic analysis of the works on this specific topic. To this end, this paper presents a systematic review of contributions on relief distribution networks in response to disasters. Through a systematic and scientific methodology, it gathers and consolidates the published research works in a transparent and objective way. It pursues three goals. First, to conduct an up-to-date survey of the research in relief distribution networks focusing on the logistics aspects of the problem, which despite the number of previous reviews has been overlooked in the past. Second, to highlight the trends and the most promising challenges in the modeling and resolution approaches and, finally, to identify future research perspectives that need to be explored.

Keywords: *Relief Distribution Networks, Emergency Logistics; Humanitarian Logistics; Emergency Management; Response Optimization; Systematic Review.*

Introduction

Natural disasters and catastrophes have always been part of the world's reality. Even with today's technology and advancements in disaster planning on our side, disasters' related casualties and financial losses can be very high. For example, March 2011 Japan's earthquake and tsunami resulted in more than 15 800 deaths and 3 600 missing persons[1] in the Tohoku district only, and over 210 billions of dollars in economic losses[2]. Due to the multiple natural and man-made catastrophes happening all over the world, the scientific community is increasingly interested in developing knowledge on Emergency Management (EM), an emergent multidisciplinary research field aimed at helping and enabling communities prepare for disasters and respond to extreme events.

In the last years, a large number of scientific contributions have been made to the EM field Although classed under the EM umbrella, they differ greatly in regards to objective, scope, and motivation. For example, we noticed that terms like "*emergency*", "*emergency logistics*", "*humanitarian logistics*" and "*response to crisis*" are used in a wide range of contexts not related to relief distribution networks. When looking at the notion of emergency management, important distinctions must be made between daily emergencies, crisis situations and EM.

EM, also known as disaster management, can be defined as a discipline dealing with disasters related risk (Haddow et al. 2007). According to the International Federation of Red Cross and Red Crescent Societies, a disaster is "*a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources.*"[3] Considering this, a distinction between emergency management and *daily emergencies management* must be made. Contrary to disasters, daily emergencies are usually well handled by the affected community's daily operations. Therefore, the context, challenges, urgency and impact of the operations in both cases are quite different. This was underlined by Simpson & Hancock (2009) who presented a review of 50 years in emergency response, covering

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[1] Damage Situation and Police Countermeasures associated with 2011 Tohoku district - off the Pacific Ocean Earthquake - November 22, 2011 - http://www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf

[2] EM-DAT data base, Disaster profile: Earthquake (seismic activity): http://www.emdat.be/result-disaster-profiles?disgroup=natural&period=1900%242011&dis_type=Earthquake+%28seismic+activity%29&Submit=Display+Disaster+Profile

[3] http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/what-is-a-disaster/

the period between 1965 and 2007. The authors showed the literature's shift in recent years, leaving the daily applications and turning more to disaster related emergencies.

Crisis management refers to different types of crisis and a large set of contributions may therefore be referenced under that term. Natarajarathinam et al. (2009) reviewed publications pertaining to supply chain management (SCM) in times of crisis. The literature selected by the athors's focused on SCM disruptions i.e. business logistics reacting to unexpected crisis, either internal (company crisis) or external (sudden-onset and slow-onset disasters, financial crisis, market crises, etc.). A small part of the review related to catastrophes, defined as a part of external crisis.

EM is a discipline of continuous work on infrastructure and peoples' awareness. Altay and Green (2006) were among the first to review the available scientific papers using Operations Research and Management Science (OR/MS) applied to EM. Their review of articles published between 1980 and 2004, provided statistics and classified contributions based on the approach, the phase of application, the review of publication and more. Galindo & Batta (2013) added to this work by reviewing papers from 2005 to 2010 and following up of the conclusions of Altay & Green (2006).

From a chronological standpoint, the literature often divides the EM's continuous process into four different phases (Altay & Green 2006; Haddow et al. 2007; McLoughlin 1985) : mitigation, preparedness, response and recovery. The mitigation and preparedness phases take place before the disaster. These phases are aimed at lowering the probabilities of a disaster occuring or minimizing its possible effects. The response and recovery phases are post-disaster phases. The response phase seeks to minimize the disaster's effects by helping people as quickly as possible and preventing any more loss while the recovery phase supports the community in its effort to return to a normal state. The actual division of these phases will be discussed further on.

Many academic publications have contributed to the research done on one or more of these phases. According to Altay & Green (2006) and Galindo & Batta (2013) more than 264 papers have been published on EM and a special attention has been given to the response phase. More than 33% of the papers included in both reviews focused on the response phase, in which the major activities are logistic oriented (e.g. opening shelters, relief distribution centers, medical care and rescue teams dispatching, etc.). Indeed, we have come to conclude that 80% of EM concerns logistic activities (Van Wassenhove, 2006), reason why emergency logistics (EL) is a very popular research application nowadays.

Motivation for a relief distribution networks literature review

Many authors have acknowledged that the particularities of the emergency management context bring on some new challenges, especially in regards to logistics optimization (Holguín-Veras et al. 2012; Kovács & Spens 2007; Sheu 2007b; Van Wassenhove & Pedraza Martínez 2012). Very recently, Holguín-Veras et al. (2012) published a paper on the unique features of post-disaster humanitarian interventions. Their work elaborates on the differences between interventions made during the immediate response to disasters, and those made in the recovery phase. These efforts may also be divided into short-term and long-term recovery activities. The long-term recovery activities can be included in regular humanitarian actions carried out in the long term. Regular humanitarian actions also include the response to slow-onset disasters, like the delivery of food to regions afflicted with chronic crises or the delivery of medicines to people in developing countries, and have a more stable environment of operations. On the other side, the logistical efforts required by an immediate post-disaster's response distribution are made in extreme conditions and therefore demand new ways of organizations. The varying networks' goals, the associated organizations, the participants' interactions and the pressing nature of the distribution are all motivating factors in the elaboration of a new logistic structure's framework able to cope with these challenges. We recommend Lettieri et al. (2009) and Kovács & Spens (2007) for a review. Lettieri et al. (2009) also presented an analysis oriented on a disaster management theoretical framework, the phases in EM, the actors involved and the technology (DSS, GIS, etc). In order to define a general framework for the relief supply chain, Kovács & Spens (2007) included both academic and practitioner journals in their topical review. Without a doubt, an analysis of the distribution network's management challenges is vital to the development of DSS and tools for crisis managers. However, a large portion of the literature is devoted to the logistics aspects of the relief distribution. Holguín-Veras et al. (2012) highlighted the urgency in understanding the workings of the relief distribution network in specific logistics' aspects, like the knowledge of demand, the considered objectives, the periodicity and the decision-making structure. Until now, these major differences had been neglected, and our work comes to support the analysis that researchers need to do in order to approach this complex problem. Figure 1 presents the specific interest of this review pertaining to relief distribution networks and its related fields.

Within the specific field of relief distribution networks, two recent literature reviews are relevant to our work. Caunhye et al. (2012) analyzed logistics optimization papers in a pre and post disaster context. Even if the motivations and global scopes are close to ours, our results showed that the authors' methodology (Content Analysis) left a good number of papers out their review. In addition, we can add to their work more than 40 papers published between 2010 to 2013. Likewise, de la Torre et al. (2012) presented a review of academic and practitioner papers on the Vehicle Routing Problem (VRP). The main characteristics of the papers reviewed and their relationship with the academic/practitioner's point of view are presented. However, due to differences in motivation and scope, several academic contributions are not included in their review.

That being said, we believe that there is a need for a narrow literature review specifically focused on recent contributions in relief distributions networks because (1) the number of contributions to the field is larger each day, and it seems to keep on growing even faster; and (2) this crucial issue in EM requires that a specific analysis of the literature be devoted to it. In this context, our work pursues two main objectives. First, to provide a systematic review covering and classifying the numerous available studies in order to consolidate the body of knowledge. Our review process, which allows us to cover a large number of contributions, along with our classification framework, will provide a recent and organized overview of new optimization tools in the hands of emergency managers. In addition, this systematic review will become a powerful tool for introducing students and people interested in the discipline. Secondly, the evolution of this discipline needs to be studied, and especially the specific logistics features. This review will allow us to present the field's state of the art, highlight the literature's most significant contributions and, even more important, identify new research areas that need to be explored.

The rest of this article is organized as follows. Section 2 describes the process used to find and select the studies included in this review. Section 3 reports our research results, in which the research topics in relief distribution networks are summarized. The following four sections (4 to 7) present the papers' trends in each of the identified research topics. Section 8 provides a general discussion of our research results and future research recommendations, and section 9 draws our global conclusions.

2. Methodology: Systematic selection process

In order to cover as many pertinent documents as possible and given the variety of scientific papers in emergency logistics as well as the growing number of contributions, a systematic approach was required. This section presents the methodology used to guide the articles' selection process: the systematic review methodology (Kitchenham 2004; Staples & Niazi 2007; Tranfield et al. 2003). Although the systematic review methodology originated in the medical field, it has recently been applied to management topics. Tranfield et al. (2003) state that a systematic review is a key tool in developing the evidence base. The main objective of this methodology is to increase the quality of the review process by synthetizing research in a systematic, transparent and reproducible way. Indeed, every review process needs a framework definition subject to the scope of the problem and the the research team's interests. Moreover, establishing a systematic procedure lends transparency to the review process and reduces the effects of the authors' bias. A clear and public definition of the review's objectives, the inclusion and exclusion criteria, as well as the process' results and the procedure itself, motivates the need for researchers to be explicit, consistent, and straightforward. Furthermore, the protocol's report maximizes the possibility of reduplication and even allows the continuity of the process. The methodology applied to this review can be summarized as follows:

1. The review's needs and general goals were established. Faced with the emergency logistics literature's state, with numerous and diverse contributions, our team felt the need for a detailed picture the research done on relief distribution networks. More precisely, this systematic review is about the relief supply chain deployed in immediate response to disasters. This meant that, the literature reviewed had to include an Operational Research (OR) component with the goal of optimizing the distribution center location, resource allocation, or humanitarian aid transportation after a disaster, as well as others logistics tasks, for relief distribution, as it was shown in Figure 1.
2. With this general thought, five relevant databases were selected as search engines for our process. Three of them were related to administration sciences: ABI/Inform Global, Academic Search Premier and Business Source Premier. The other two were OR oriented: Compendex for engineering and technology, and Inspec for calculations in physics, electronics, and information science. A multi-disciplinary database was included: ISI' Web of Science.

3. Based on our knowledge and expertise in the field, as well as the review of 20 well-recognized references in the literature, a set of key words was selected to define two search chains. These search chains were identified in the title, abstract, citation and/or subject of the articles. The words used our search chains were emergenc*; disaster*; catastroph*; "Extreme Events"; Humanitarian*; Aid; Assistanc*; Relief*; Logistic*; "Supply Chain"; Response; Distribution. The word "optimization" created an enormous restriction of the results and so, it was not considered in our search chains.

4. To help us to restrict our search results, a date range was defined. We only considered works published between 1990 and 2013. This decision was justified by the fact that the most significant advancements in the EM research field were done in the last decade. In addition, the previous studies focused on nuclear emergency response, a strong trend in the 1980s. At the time, emergency management was not really structured or formalized (Altay & Green, 2006).

5. The great number of search results and the variety of contributions required that boundaries be established to limit the number of "hits". Different inclusion and exclusion criteria were defined and applied to our selection process. Before presenting these criteria, it is worth mentioning that this paper does not intend to be an exhaustive bibliographic study, but the result of a systematic scientific review method in the specific field of relief distribution networks.

The review's inclusion and exclusion criteria used to narrow the search results are as follows:

Inclusion and exclusion criteria

We chose to limit our search to academic publications with a peer review process. We excluded all governmental and military reports from our selection as well as practitioner reviews research made by private organizations. Conference acts, congress papers and dissertations were also excluded. Other papers (e.g., case studies, response performance analysis or reports from EM organizations, such as the Federal Emergency Management Agency (FEMA), the United Nations (UN) or the International Federation of Red Cross and Red Crescent Societies (ICRC)) were excluded as well.

On the other hand, to reflect our interest in the response phase, the contribution proposed by the articles selected had to be designed keeping in mind it's application in the aftermath of an extreme event. This aspect was sometimes difficult to evaluate precisely because some papers can be applied in either the preparedness phase or the response phase, depending on whether or not the input data were predictions or real observations. In the latter case, they were included in this review.

Studies about preparedness activities, which are intended to be applied in advance of a disaster (e.g., evacuation planning, congestion analysis problems, provision sourcing selection and stock prepositioning for a long-term context) were also excluded from our review. Likewise, we excluded research on the recovery phase, in which the planning horizon defined for the problem is longer than the one for the response phase. Also, the research objective had to have a more strategically sustainable perspective. Although not considered in this review, we tend to point out the interest of these papers and the importance of their contributions.

Furthermore, given the large number of papers and the context particularities, we limited our search to papers considering sudden-onset disasters only (Van Wassenhove 2006), such as the 9/11 terrorists attacks in NYC or the earthquake in Haiti in January 2010. This means that the relief distribution in a slow-onset disaster context (e.g., famine or drought) is out of our scope.

6. After establishing the review's boundaries, the search process was executed in the different databases. The search was executed in two phases. A first databases search was conducted in June 2011, and 4169 papers were found. Then, as an update, we proceeded to a second in June 2013. We looked for papers published between June 2011 and June 2013, finding 368 new papers. A total of 4537 papers were found by the search engines. The title and abstract of the search results were considered and compared to our inclusion and exclusion criteria. This first filter left a total of 107 papers for further analysis. Additionally, the following additional sources were consulted to make the research as rich as possible: (1) a previous search in the references of the initial databases of the well-known articles led to the addition of 22 new references. (2) Futhermore, our search protocol led us to the discovery of seven previously published special issues in emergency management: Transportation Research, Part E, Vol. 43, No. 6, 2007; International Journal of Physical Distribution & Logistics Management, Vol. 39, No. 6, "SCM in time of crisis humanitarian," 2009; International Journal of Physical Distribution & Logistics Management, Vol. 40, No. 8-9, "Transforming humanitarian logistics," 2010; International Journal of Production Economics, Vol. 126, No.1, 2010; OR Spectrum, Vol. 33, No. 3, 2011; and Socio-Economic Planning Sciences Volume 46, Issue 1, "Special Issue: Disaster Planning and Logistics: Part 1" and Volume 46, Issue 4, "Special Issue: Disaster Planning and Logistics: Part 2", 2012.

A total of 56 papers were found in these special issues. 23 of them were found in databases using our search system. The other 33 references that had not been found or selected were explored, and 13 of them were retained for a deeper analysis. (3) The references from the 16 articles of OR Spectrum, as well as the references from the six reviews papers, were explored to add 28 new references. We discovered that, in most cases, the mix of keywords defined by the authors was the reason behing the exclusion of those references from our original search results. A total of 170 papers were set apart for a more thorough reading. The 170 papers selected were read, analyzed and once again compared to our inclusion/exclusion criteria. This lead to the final set of 83 papers reviewed in this article.

3. Research topics in relief distribution networks literature

Generally speaking, the study of relief distribution networks includes the following sequence of decisions and tasks. Once the emergency alert is given, the authorities (who may be regional, national or even international, depending on the scale and gravity of the crisis) on the scene evaluate the situation. The affected zone, also called the *hot* zone, is delimited, and the logistics deployment starts. One of the first decisions to be made concerns the design of the distribution network and consists in electing the set of logistics centers, shelters and distribution centers that will be used to support the relief operations. Located in a safe area outside the hot zone, large distribution centers (DCs) receive and consolidate relief goods from external suppliers. DCs feed humanitarian aid distribution centers (HADCs) located inside the hot zone. HADCs distribute relief goods to the points of demands (PODs) which in fact represent a cluster of affected people. Usually, the site's selection for the DCs and HADCs is done from a set of pre-selected sites identified, and even prepositioned, during the preparedness phase. The second type of decisions in the logistic deployment concerns the allocation of available resources to HADCs taking into account the needs of the affected people they will be serving. The third type of decisions relates to the transport between HADCs and PODs. Emergency logistic networks imply an inbound flow of relief from the cold to the hot zone, but also an outbound flow aimed at moving people or materials towards safer areas located either inside or outside the hot zone. Despite of the importance of such outbound flows, this review focuses on the inbound part. Figure 2 presents a diagram of the general emergency logistic network.

Our review process shows that the literature is well aligned with this decisional framework. Therefore, the papers reviewed were divided into the following categories: (1) location/allocation and network design problems, (2) transportation problems, (3) combined location and transportation problems, and (4) other less popular, but still important, topics in relief distribution. Note that, given that our interest is limited to relief distribution networks, the resource allocation problem is only defined for the commodities and capacity assignments in the HADCs. In most cases, this aspect is covered in the network design decisions.

Table 1 reports the articles found in each of these categories. 29 articles out of the 83 selected papers are devoted to the location and network design problems and were published between 1991 to 2013. 30 articles focus on transportation problems; eight articles tackle both location and transportation problems either in an integrated or a sequential manner and, finally, 16 papers deal with other important topics, like dynamic demand management, prevision and road repairing, among other subjects.

Categories taxonomy

Before going into the details of each category, we propose a taxonomy used to classify and position the contributions of the reviewed articles according to general OR characteristics or criteria. This taxonomy will help identifying research trends in emergency logistics, classifying the different versions of problems, the considered attributes, and the modelling approaches proposed.

The first classification criterion refers to the type of data modelling approach used by the authors and, in particular, by the inputs' characteristics (i.e. demand, capacity, impacts or damages caused by the event…) considered by the models. In most cases, these aspects are generally modelled as either static or dynamic inputs. More precisely, some authors represent these inputs as a stochastic process with random variables, or even as fuzzy problems with fuzzy variables.

The second criterion concerns the scope or the decisional perimeter of the problem under consideration. It consists of classic OR elements like whether or not the research problem (i.e., location, transportation or other problem) is a single or a multi objective optimization problem, if the planning horizon encompasses one or more periods, if the network transports a single or several commodities, and the kind of main objective optimized by the model. This objective can be: (1) economic (i.e. cost minimization); (2) covering maximization objective (either demand or distance); (3) rapidity (minimization of the travelling time between network nodes); (4) social cost (fairness or similar); or (5) other.

The third criterion concerns the problem solving approach proposed by the authors (i.e., exact or heuristic methods). Finally, the column Tested over specifies if the proposition was applied over academic instances (Acad.) or real life inspired instances (CS). Clearly, many other classification taxonomies may be used, but we think that those used represent a good compromise and correspond to the most desired information. This general classification was applied to all the articles reviewed. Some other considerations or criteria will be presented later on when analyzing specific works.

4. Location and Network Design

In logistics deployment, the network's design is the first decision faced by the crisis manager. Among the network's design decisions, the selection of the HADC from a set of potential sites is the foundation to the location problem. Table 2 presents the different contributions devoted to this question. In addition to the classification features defined in the previous section (i.e., Data Modeling, number of objectives – Objective, Periods, Commodity, and Resolution Method), we added three additional characteristics that are important to location and network design problems: capacity limits, sourcing considerations and the resource allocation approach.

The Cap. Limits column shows whether or not the model deals with a capacity limit in potential location sites. This consideration evidently adds constraints to the problem and makes it more difficult to solve. The Sourcing column indicates whether or not the authors restrict the supply sources. A single-sourcing restriction means that a client is forced to be supplied from only one depot; conversely, multiple-sourcing means that a client can be reached from various depots. Lastly, the resource allocation (RA) column lets us know whether or not the authors included resource allocation decisions (e.g., capacity allocation, stock prepositioning, or client's assignment) in their model.

The papers reviewed in this section are classified in two different categories, according to where the authors placed themselves on disaster response timeline (i.e. before or after disaster occurrence). The first type are the location decisions defined for a Post-event context, allowing authors to consider that, as we explained before, the evaluation of the affected zone is already done and the disaster effects and major needs are known to crisis managers. This hypothesis creates a “steady” environment that allows propositions in this category to define, as an input known a priori in the model, the demand and the location of clients, as well as the disaster impacts. Our review shows that the articles in this category present a more traditional facility location problem (FLP) structure, they are mainly static and seek to optimize a single objective (either cost minimization, covering maximization in distance or quantity or rapidity) and this, during a single period. In addition, most of the location and network design problems are directed to a single-commodity relief distribution, representing a global demand. Horner and Downs (2007; 2010), present a multi-echelon network designed for intermediate distribution facilities (Break of Bulk points). Iakovou et al. (1997) present the strategic and tactical decisions involved in locating the clean-up equipment for oil spill disaster. Other authors deal with the location-allocation of medical services in response to emergencies with a covering objective, forcing a minimum satisfaction of demand such as (Jia et al. 2007a; Jia et al. 2007b), and (Lee et al. 2009a; Lee et al. 2009b).

However, models able to accurately represent the disaster reality may be more desirable. Indeed, even after a disaster has hit the zone, information about demand is hard to obtain, and a stochastic modeling approach can be useful to represent the incertitude related to the process of the impact’s estimation. Recent contributions tackled this issue with stochastic models that maximized coverage (like Murali et al. 2012), models reflecting post-disaster challenges as disaster overlapping (Zhang et al. 2012), or fairness in distribution objectives (Lin et al. 2012). It is worth mentioning that, as we indicated before, the contributions in this section still present the classic structure of the FLP applied to emergency situations, without real insight into the context difficulties being reflected in their models. With the recent exception of the papers published in 2012, neither the objectives nor the constraints of the model present a particular feature in relief distribution. We firmly believe that these recent contributions come as an answer to the need for detailed models that supporting decision- making.

The second group contains the propositions with a Pre-event context. The strategic nature of the location problem has encouraged many authors to work on the right network design in order to prepare for disaster response. Even though our article selection process is limited to the relief distribution network in response to disasters, these models can also be applied as an immediate response to the disaster; therefore, these propositions are included in this review. Moreover, many contributions in this section actually consider both stages in their modeling approach, dealing with stock prepositioning decisions, and then reallocation after a disaster occurrence. For instance, some of the papers present stochastic models, in which the site location is chosen to satisfy demand under different possible disasters (Rawls & Turnquist 2010) or their impacts: Balcik & Beamon (2008) also includes pre and post disaster budget constraints; the service quality level (Rawls & Turnquist 2011); the possible locations of disaster related damages (Campbell & Jones 2011) or multilevel considerations for network design (Chang et al. 2007). Recently this has starting to shift towards a prepositioning problem that includes, beyond the risk of damages (demand), the demand location (Rawls & Turnquist 2012), available supplies (Davis et al. 2013), outsourcing needs (Nagurney et al. 2011) and even transportation and buying costs (Bozorgi-Amiri et al. 2012). Wilhelm & Srinivasa (1996) focus on the risks related to the reliability of the relief distribution network, which is still present in a post-disaster context. Other authors concentrate their efforts more towards a model definition with the main objective warranting relief distribution to its maximum capacity. In this case, a covering objective is used to minimize uncovered demand (Drezner 2004; Drezner et al. 2005; Görmez et al. 2010; Hong et al. 2012), including characteristics as social cost (Yushimito et al. 2012) or covering and rapidity objective (Zhang et al. 2012).

Three papers considered the sheltering location (and allocation) problem in a pre-disaster context. Even though they are evacuation-oriented, these papers were retained, because the location decisions for the evacuation problem at this level are the same as for the distribution context. Kongsomsaksakul et al. (2005) and Sherali et al. (1991) defined an optimal sheltering network that minimizes transportation time, while Li et al. (2011) proposed a two-stage stochastic model to consider the shelter supply.

Aside from the points discussed before, our review shows that most of the authors, both in a pre and a post disaster context, kept the strategic aspect of the location problem in a single period planning horizon and a highly aggregated information level on demand having a single-commodity feature (i.e. only 10% of the papers include a multi-period feature and 30% a multi-commodity network). We see this as particularly odd, given the fact that the in the context of immediate response to disaster the planning horizon is more likely short, and networks need to be very flexible. In addition, over 50% of the papers have a cost minimization objective, which has been already accepted as a limited and inappropriate objective for the relief distribution networks.

Furthermore, almost 30% of the papers reviewed propose a maximum covering objective as main objective, p-media problem or p-center problem, which are common models in FLP. These models are focused on the covering of PODs in terms distance only (i.e. a POD is covered if an open HADC is inside a maximum distance). However, they usually ignore the resources' availability and total satisfaction is assumed. Another common hypothesis in the FLP is that the HADCs' supply is unlimited. Therefore, very few papers consider the upper level of supply (DCs) in their network design. A deeper analysis is needed in both of these areas in order to design a network that would include the demand satisfaction's real capacities.
Even if there is indeed a strong need for efficiency in the use of resources, other objectives like social cost or rapidity in distribution should be the main guideline for the network's design decisions. Lifting these hypotheses will result in contributions not only more realistic but also more likely to be useful in a complete DSS.

5. Transportation Problems

Once the logistic network has been established, the relief delivery plan has to be built, leading to transportation or distribution problems. Until very recently and because of the number as well as the variety of propositions, this topic was the most popular in emergency logistics research, In fact, we noticed that transportation contributions are closer to the specific challenges of relief distribution. Thanks to the operational basis of the transportation task, the problem definition of these contributions is more specific to the response to disaster context and allows for the definition of a more practical distribution problem. For instance, the objectives defined in the contributions' transportation problem are more varied than for location cases and focus more on the distribution's rapidity or the satisfaction of demand than on total operational costs.
Since the transportation problem's characteristics changed, the table structure proposed in the previous section was modified, leading to Table 3. The first four columns show the already defined general characteristics. The fifth is the Depots column, indicating if the problem is defined as a single depot or multiple depots. Then, some vehicle's characteristics of the model are observed. The Capacity Limits column summarizes whether or not the proposition limits the vehicle's capacity. This column shows the limitation considered: volume capacity, weight capacity, distribution time of the driver's shift, cost, number of vehicles available, or the number of units to transport. The seventh column, Fleet Comp., shows whether the model uses a

heterogeneous fleet of vehicles or homogeneous fleet to construct the route. This is an important feature in humanitarian logistics because several organizations are involved in emergency response activities and the need for numerous types of resources (i.e., vehicles) is very common. Finally, the column Tr. Mode shows whether the problem is stated as a multi-modal problem or the specific type of transportation mode (i.e., ground, air or water). The different papers concerned with relief transportation decisions are presented in Table 3.

It is well accepted that transportation and routing problems are very difficult to solve. Even in the industrial context, academics and practitioners have been working for decades on this optimization problem. The problem's difficulty increases as the model's level of detail increases. If we deal, all at the same time, with stochastic data, heterogeneous vehicle fleet, in a multi-period and multi-commodity network context (which is probably the closest to reality), the resulting model will be extremely hard to solve; which is not at all wanted when looking for fast and efficient solutions. Therefore, authors will usually choose the factors that best adapt to their study context and will establish hypotheses on the other features to simplify the model. For instance, some authors have a traditional approach to the data type (e.g., a deterministic static or dynamic data model) in order to consider a multi-period planning horizon (Wohlgemuthscha et al. 2012; Yuan & Wang 2009; Zhang et al. 2013) or a multi-commodity network (Berkoune et al. 2012; Gu 2011; Hu 2011), or even both (Balcik et al. 2008; Haghani & Oh 1996; Lin et al. 2011; Özdamar et al. 2004; Sheu 2007a; Tzeng et al. 2007). Even though their data setting is deterministic, these papers define a complex distribution network close to the relief distribution's reality, with a proper level of detail to reflect the crisis manager's challenges. We believe this to be a very important point to establish models for decision making for the daily operations of relief distribution.

On the other side, some authors have a "traditional" approach to their problem's characteristics (i.e., static data, single-commodity and single period considerations) but with the objective of exploring new approaches to the relief distribution problem. For example, the transportation contributions have varied objectives beyond cost minimization. The most popular objective regarding these problems is the rapidity objective, usually defined through a minimum travel time objective or a minimum latest arrival time. Campbell et al. (2008) were among of the first to explore the major difference between relief and commercial distribution by proposing three different objectives for a fast delivery. Chen et al. (2011) defined a distribution problem integrated in a DSS with the support of a Geographic Information System (GIS). Suzuki (2012) had a static consideration but studied a coverage and equity objective that also included fuel limitation. On the other hand, Huang et al. (2012) defined three main objectives for the relief distribution challenge: rapidity, demand satisfaction and equity (i.e., equity, efficacy and efficiency). Theirs was one of the first propositions to approach the equity objective in an explicit way.

Through random or fuzzy variables, many authors also considered the uncertainty related to the relief distribution context that are reflected in demand, arc capacity, travel time or network reliability (Adivar & Mert 2010; Barbarosoğlu & Arda 2004; Shen et al. 2009; Vitoriano et al. 2009; Vitoriano et al. 2011). These papers' main contribution acknowledges the different sources of uncertainty in a post-disaster context, thus providing crisis managers with a more robust distribution plan. However, these contributions left aside the dynamic aspect of the problem and focused on a single period planning horizon. We believe this to be a useful twist that should soon be included in the emergency logistics planning. As we stated before, the changing environment is an important challenge in this context and a flexible network is still a major need.

When working on transportation problems, one should also consider the problems related to the transportation of casualties. During our review process, we noticed how the evacuation's planning decisions demand another type of analysis on an operational level (i.e., traffic assignment problems and congestion analysis, among others), which are out of the scope of our review. Contrariwise, the casualty transportation problem is sort of a "victims' transportation problem" and is part of the tasks needed to bring relief to affected people, which allowed us to review casualty transportation problems in this paper. In fact, some authors tackled both relief distribution and casualty transportation problems in their optimization model. In general, the model finds the optimal route to distribute relief products and transport victims from the danger zone to health centers. This results in a much more complex network problem, becoming a multi-commodity problem often presented with a multi-period planning horizon. Some of them have a static data setting, planning helicopter scheduling (Barbarosoğlu et al. 2002; Özdamar 2011) or a heterogeneous vehicle problem (Özdamar & Demir 2012; Özdamar & Yi 2008; Yi & Kumar 2007). Others present a dynamic problem (Chern et al., 2010) or a fuzzy stochastic problem (Najafi et al. 2013; W. Yi & L. Özdamar 2004). Finally, in their paper, Jotshi et al. (2009) dealt exclusively with the casualty transportation problem.

In general, one of the features common to most of the contributions' modeling approach is the use of a heterogeneous vehicle fleet that even considers a multi-modal problem. We believe this to be an interesting feature to include in the modeling process of relief distribution optimization for two main reasons. On one hand, it is one of the classically features studied in transportation optimization. The number of models and resolution methods that consider the variety of the fleet (in capacity, cost, use and/or purpose) is quite large nowadays, and this give even more tools to academics and practitioners to define applied problems. On the other hand, considering a heterogeneous fleet and, even more, a multi-modal context in their problem definition opens the door to include the variety of actors involved in relief distribution tasks. Indeed, different government, international agencies, NGOs, and even private sector participants put their resources together to overcome a crisis. Therefore, even if the advancements on this area are significant, and over 50% or the papers reviewed include a heterogeneous fleet, there is still a good opportunity to further explore this area and make the relief distribution process even more efficient.

Finally, another common feature in the transportation contributions is the consideration of a multi-depot network in order to elaborate the distribution plan (almost 60% of the reviewed papers acknowledge this reality). We encourage this practice because, as with the fleet composition feature, a multi-depot consideration will enable the crisis managers to plan not only a more complex and realistic network, but will also promote a better distribution of resources available, helping them to cope better with products' shortages.

6. Combined Location - Transportation Problems

As we stated before and as proven by the various contributions reviewed in the previous two, the location and transportation problems are the two main stages in relief distribution management. The OR literature has already established that the location problem's decisions have a direct influence on the efficiency of the distribution tasks. The choice of depots, as well as the center's required capacity, directly affects the distribution decisions. Therefore, the natural evolution for the decision optimization process is to approach these two problems from an integrated perspective that includes the analysis of the interrelation between these two decisional levels. Many contributions have been made on one stage or the other, but the integrated-approaches are still rare. Only 8 of our 87 reviewed articles have tackled the location and transportation problems together. These articles and their characteristics are presented in Table 4. Some of them addressed the problem in an independent sequential manner (Mete & Zabinsky, 2010; Zografos & Androutsopoulos, 2008), with a stochastic or static data setting. Nolz et al. (2010, 2011) and Naji-Azimi et al. (2012) presented a tour-covering problem in which the routes are constructed, integrating the site selection decisions inside the covering zone. Ukkusuri & Yushimito (2008) and Yi & Özdamar (2007) presented an integrated Location-Routing Problem (LRP). Ukkusuri & Yushimito (2008) used this modeling approach for the stock prepositioning and distribution problem, considering the path's reliability. Yi & Özdamar (2007) solved a complex distribution problem, including casualty transportation. Based on dynamic demand's updates, the model will decide to open new care centres. An interesting contribution has recently been made by Afshar & Haghani (2012) who proposed a detailed complex network design and transportation problem to develop an integrated decision problem.

7. Other contributions

Some articles highlight a research problem that is less popular than the location or routing problems, but still represent an important advancement in relief distribution networks. For example, many authors chose to approach resource allocation independently of the location or the transportation problems. These contributions are specifically oriented to inventory location or relocation before and/or after a disaster occurrence (Lodree Jr et al. 2012; Rottkemper et al. 2012; Rottkemper et al. 2011), and others treated the equipment allocation (Altay 2012; Minciardi et al. 2007; Minciardi et al. 2009), dealing strictly with the resource allocation problem where the real-time dynamic aspects of problems are approached.

On the other hand, (Duque & Sörensen 2011; Feng & Wang 2003; Viswanath & Peeta 2003; Yan & Shih 2009; Yan & Shih 2007) proposed the problem of planning the urgent repairs in the response network.

Recent contributions described other specific challenges in response to disaster and relief distribution, like Huang et al. (2013) who suggested a routing problem for the assessment of the affected zone, which is probably one of the first steps in response to disaster. Usually, most of the studies use the hypothesis that this assessment work has been done before the location and transportation decisions.

Falasca & Zobel (2012) approached the specific problem of volunteer assignment which, until now, has been equally neglected. In their paper, Turner et al. (2012) proposed a water distribution using pressurized zones to satisfy the demand in uncovered areas.

Sheu (2010) and Xu et al. (2010) presented a very interesting and useful proposition to manage and forecast demand. Clearly, this is one of the major challenges in emergency logistics response and it is often ignored in the literature propositions. Sheu (2010), with the help of a multicriteria analysis, proposed a complete system that forecasts, groups and ranks the demand after a disaster. By using a hybrid method to forecast demand instead of traditional statistics, Xu et al. (2010) produced better results.

8. Literature analysis and future research perspectives

This section first presents our analysis of the reviewed papers, depicting the most recent advancements made in the field. It then identifies some research trends that are, in our opinion, the most challenging directions in emergency logistics.

Analysis of the reviewed literature

Our first observation concerns the lack of uniformity and accuracy in the definition of Emergency Management, the multidisciplinary research discipline pertaining to the particular field of relief distribution. In fact, EM is so vast and has grown so fast in the recent years that the need for scientific works devoted to the formalization of the discipline and its boundaries has become a matter of urgency. As shown in the Introduction, the terms "*emergency*", "*emergency logistics*", "*humanitarian logistics*" and "*response to crisis*", *among others,* are applied in a wide range of contexts and from diverse standpoints, making it difficult to consolidate the knowledge and the scientific contributions.

Furthermore, and despite its theoretical value, the relevance of some structuring works to the relief distribution's practice, like the 4-phases definition commonly accepted in the literature, is debatable. In fact, we have shown that many of the proposed location models for a pre-disaster phase can also easily be applied during the response phase. A response model, embedded in a Decision Support System, can be used in the training and preparedness process. Similarly, once the data has become available, a preparedness model can lead to an optimal response plan. We can conclude that, unlike the traditional approach in EM literature, the location and network design problem are not exclusive to the pre-disaster phase. Moreover, we think that the disaster timeline and the related operations need to be refined to harmoniously encompass the response as well as the short and long-term recovery activities.

Our second observation concerns the well-established differences between business and humanitarian logistics. Pioneer contributions in the field defined general response models, mostly within a multi-commodity network (Barbarosoğlu & Arda 2004; Barbarosoğlu et al. 2002; Drezner 2004; Drezner et al. 2005; Haghani & Oh 1996; Özdamar et al. 2004; Viswanath & Peeta 2003; Yi & Özdamar 2004). Despite their efforts, it seems that most of these contributions did not focus adequately in the specific characteristics of humanitarian logistics like the knowledge of demand, the considered objectives, the periodicity and the decision-making structure (Holguín-Veras et al., 2012). Hopefully, our knowledge and comprehension level of humanitarian challenges increases and recent articles present more sophisticated models, which better suit the specific context and needs, especially in the case of transportation problems (Berkoune et al. 2012; Gu 2011; Huang et al. 2012; Lee et al. 2009a; Lin et al. 2012; Lin et al. 2011; Murali et al. 2012; Özdamar 2011; Yan & Shih 2009). Nonetheless, we think that the sudden and dramatic nature of humanitarian problems should be emphasized in future research works.

Our third observation concerns the difficult tradeoff between modeling the desired level of detail and the model's solvability. As more and more sophisticated, yet realistic models appear, it becomes increasingly difficult to solve them efficiently, particularly in a response context where decisions need to be made quickly. Thereby, papers proposing approximated methods (e.g. Nolz et al. 2010; Yi & Özdamar 2007; Berkoune et al. 2012; Lin et al. 2012; Murali et al. 2012; Wohlgemuthscha et al. 2012) are becoming more and more popular than the ones, focusing in modeling aspects, where commercial software is used to solve the proposed mathematical formulation (Horner & Downs 2010; Jia, Ordóñez & Dessouky 2007; Lin et al. 2011; Rawls & Turnquist 2011).

The stochastic and dynamic propositions are still rare. Even during the response phase, the level of uncertainty and, more so, the variability level are quite high, and a deterministic static modeling approach can easily lead to a low performance of the distribution tasks. However, stochastic and dynamic models being much harder to solve, significant effort is needed to efficiently the solve the propositions.

Our fourth observation,which is in fact a set of observations, pertains specifically to the works on network design. First, we think that the nature of the different nodes or sites in the network needs to be revised and refined. Although the use of distribution centers and distribution points similar to those in the business SC seems to be widely accepted, we should not forget that, in the business case, those facilities are designed and built to perform logistic activities, which is not the case in a post-disaster context. Indeed, most humanitarian sites rely on the transformation of facilities like arenas or schools making it difficult to anticipate their flows and capacity to handle humanitarian activities and. In general, the literature has neglected the aspect related to the "ability" of a facility to perform a given humanitarian and it would be interesting to see it included in future works. Even more important, we found that a very few of papers tackled multi-period cases in network design, neglecting the fact that the deployed network is usually temporary and needs to be flexible to accommodate the demand's variation. Moreover, in a multi-period planning horizon, facilities can be opened, closed and reopened during the planning horizon; therefore sites costs and capacities strongly impact the decisions. However, including this analysis and defining opening and closing costs in a manner relevant in a practical context still presents a challenge. For instance, one can account for the time and efforts required to open and prepare a given site by reducing its capacity during the period in which the site is open, while others may limit the number of sites to be open by constraining the number of available human resources to operate them.

Finally, we have already discussed the type of objectives that should direct the design decisions, and the small variety of modeling objectives (most articles present a cost minimization objective). However, while limited discussion have been devoted to justify whether or not single objective models are more suitable than multi-objective ones (Lin et al., 2012; Drezner et al., 2005), neither were about the choice of measures encompassed by the objective function.

Our fifth observation is related to works on transportation problems. It includes two comments and conclusions. Our first remark concerns once again the goal of the proposed models. The most popular objective in these problems is "rapidity", usually achieved by minimizing the total travel time or the latest arrival time. However, recent works have identified new and appealing objectives like minimization the risk associated to the loss of a truck and its load, or the fair relief distribution (e.g. Vitoriano et al. 2009; Vitoriano et al. 2011). More specifically, Huang et al. (2012) is the only paper to highlight the paramount importance of a fair sharing of the available relief among the people in need. For their part, Lin et al. (2011); Tzeng et al.(2007); Vitoriano et al. (2009) and Vitoriano et al. (2011) considered it more as a secondary objective. The notion of "equity", overlooked in the literature, becomes even more important when multi-period contexts are considered. Since available relief and demand may vary from one period to another, it seems reasonable to expect some flexibility in the way that demand is satisfied. This offers the possibility of delivering lower quantities to some people, provided that they receive higher quantities in the subsequent periods. Nonetheless, our review did not report any paper dealing explicitly with the possibility of relief backordering. We believe that this should be presented in order to offer a better support to the distribution decisions.

Our second comment on the reviewed papers relates to whether relief is distributed by truck routes or by dedicated trips. In fact, an analysis of this aspect has been disregarded in the literature, and both options are valid approaches on relief distribution. de la Torre et al., (2012) presented a review of papers on relief distribution where trucks performed delivery routes. On the other hand, other authors (see for example Berkoune et al., 2012) proposed a multi-trips approach to satisfy the PODs' demand.

Our sixth observation concerns the works that we have classified as "Combined location-transportation problems". The number of papers dealing with location-allocation problems have, without a doubt, increased very quickly in the last two years, with a total of nine papers published between 2011 and 2013 (31% of the location papers). We believe that the increasing attention devoted these types of problems indicates that there is a new research stream seeking to adopt a more integrated approach in order to cope with the diverse decisional levels related to relief network problems. As in the business SC case, where combined location and transportation problems have now been studied for several years, (Nagy & Salhi 2007; Salhi & Rand 1989) models addressing the links and dependencies of these two problems in a relief distribution context are required. Even more so, distributed modeling approaches are promising research areas and their application goes beyond the integrated location-routing problem to suit the global framework of response to disasters.

As a whole, it appears to us that research on relief distribution is now entering a consolidation phase, where academics have cumulated a good knowledge of disaster relief operations. The research approaches, originally very inspired from the business SC ones, have become more specialized and closer to the specific relief distribution context. Hence, the number of real-life inspired instances tackled in the literature is rather high, ranging from 33% in the case of transportation problems to up to 72% in the case of location and network design problems.

Trends and challenges

Nowadays, there is an increasing interest in tackling new subjects, such as the international scheme in response effort, service quality, equity and social objectives, or the integration of technological advances. See, for instance, Adivar & Mert 2010; Chen et al. 2011; Huang et al. 2012; Mete & Zabinsky 2010; Rawls & Turnquist 2011; Turner et al. 2012. Also, we are beginning to see the application of other classic OR/MS problems to the humanitarian logistics field. For example, contributions aimed at improving the organization or the management of other support activities can still be explored, especially in a dynamic real-time context (e.g., demand estimation, inventory management and personal management). Research on stock relocation and stock management (e.g., Rottkemper et al., 2011) would help supporting the response phase's daily operations better. Furthermore, the research done on casualty transportation is still very limited. To the best of our knowledge, this important topic has only been addressed by Jotshi et al. (2009), and the few combined flow contributions (like Özdamar 2011).

In addition, coordination is a challenging subject that still may be improved upon. However enough has been said on the importance and critical stage of coordination in humanitarian logistics and we now need to find a ways to for it to merge with the logistics optimization problems (e.g. coordination level indicators, collaboration planning models, etc.).We firmly believe that a deeper analysis of this area by way of a wider, probably hybrid, modeling approach could achieve the integration of these relationships.

Meanwhile, additional efforts need to put forth to increase the coherence between the hypothesis and considerations used to design the relief distribution networks and the decisions actually made in those networks. We still find discrepancy and separation in, among others, the objectives sought by the optimization and the manager's problems, the hypothesis, the planning horizons and the limitation of resources. In this sense, the alignment of objectives must not only be achieved through the logistic network stages (the different problems) but also through the different levels of the distribution chain (external supply sources, supply, temporal distribution facilities, final distribution). Our research shows that this aspect of relief distributions optimization network can be explored further (e.g. recent contributions like Adivar & Mert 2010; Afshar & Haghani 2012).

Finally, we believe that the next step in the optimization of relief distribution networks path is start bringing research and practice together, especially since the final goal of this research field is to improve the crisis managers response's capacity by supporting the decision-making process. In this sense, researchers are more and more concerned about defining practical and measurable objective functions. Also, increasing attention is being given to the development of integrated decision support systems (DSS), allowing crisis managers to interact, in real-time or pseudo real-time, with models and algorithms. In order to support these integrated models, we need newer solving tools able to optimize large instances in a very short time.

9. Conclusions

This article presents a systematic review of the literature on relief distribution networks. Our review focus in one of the most popular and fast-growing field of the last 5 years. A scientific research process was designed and executed to explore more than 5000 references. A transparent, systematic selection process was then applied to highlight 83 relevant articles for review. By doing so, we were able to efficiently gather and present a detailed portrait of relief distribution networks' situation. Our research shows that the scientific community has developed a growing interest in EM and many the contributions were done on the optimization of relief distribution systems in response to disasters, focusing on two major areas: (1) location and network design problems and (2) transportation and routing problems. The first problem usually dealt with during the disaster preparedness phase, but it can, and should, be extended to response phase. The second problem develops vehicle management and routing problems in a relief distribution context.

The challenge for the academic community is now to focus on designing more complex but realistic models that actually reflect the difference with the classical SCM approach. The new objectives, hypothesis, capacity limits, and planning horizon, among others, are trends in this field. In addition, we recognize the need for integrated and harmonized models, which better support the crisis managers' decisions, considering other logistic activities, such as demand management, resource allocation or inventory management. Furthermore, we acknowledge that this level of detail demands efficient resolution approaches. A strong challenge is lies in the development of resolution methods, in which advanced heuristic proposals can enhance the complex modeling process to support decision-makers in the race for an efficient relief distribution. We hope that this paper provides a good guideline to academics interested in the field so it can continue to grow; but also to practitioners, so it can be complemented and translated into a truly effective relief distribution network.

Finally, we can conclude that, both from a theoretical and a practical point of view, this research field is not only interesting, but crucial. On the theoretical side, the advancements in this research field complement the general logistics research. In fact, many things have been said about the possibility of cross learning between emergency and business logistics (Van Wassenhove, 2006; Kovács & Spens, 2007). From the practical point of view, advancements in location and distribution problems in emergency logistics, are important tools in improving the quality of response to disaster, which is the key to saving more lives.

Acknowledgements

This research was partially supported by grants [OPG 0293307 and OPG 0172633] from the Canadian Natural Sciences and Engineering Research Council (NSERC). This support is gratefully acknowledged. The authors are grateful to the anonymous referee for his/her useful and constructive comments and suggestions.

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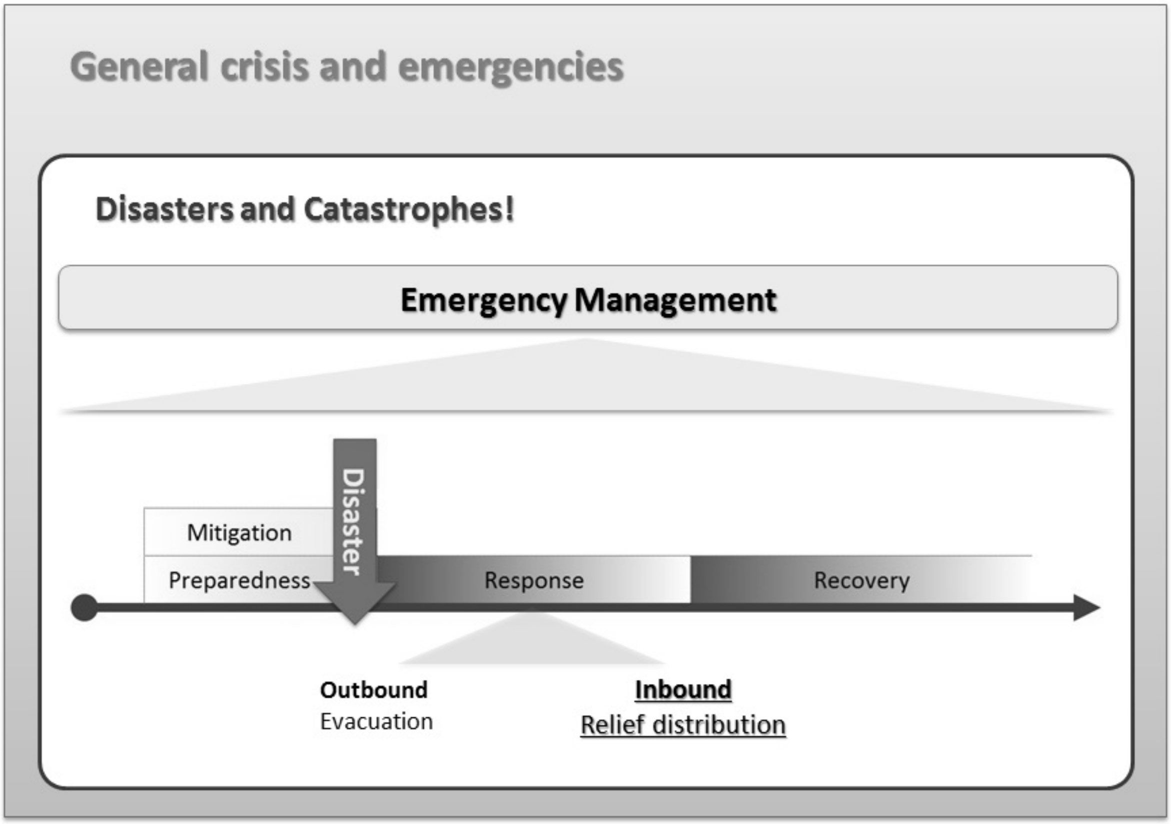

Figure 1: Relief distribution networks domain

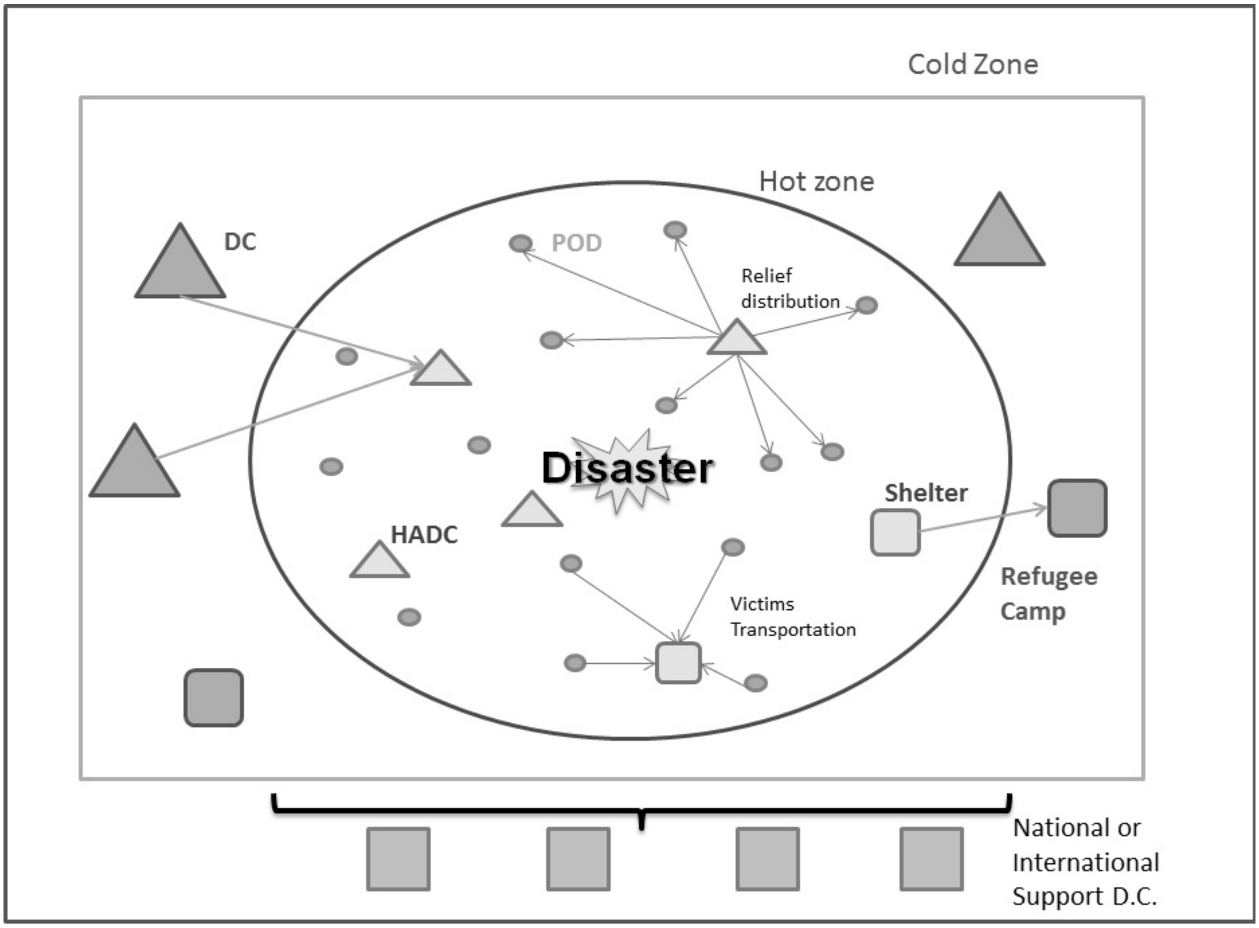

Figure 2: Emergency Response Logistic Network

Table 1: Research topics in emergency logistics

Research Problem	Total	Articles
Location and Network Design	29	Balcik & Beamon 2008; Bozorgi-Amiri et al. 2012; Campbell & Jones 2011; Chang et al. 2007; Davis et al. 2013; Drezner 2004; Drezner et al. 2005; Görmez et al. 2010; Hong et al. 2012; Horner & Downs 2010; Horner & Downs 2007; Iakovou et al. 1997; Jia, Ordóñez & Dessouky 2007; Jia, Ordóñez & Dessouky 2007; Kongsomsaksakul et al. 2005; Lee, et al. 2009a; Lee, et al. 2009b; Li et al. 2011; Lin et al. 2012; Murali et al. 2012; Nagurney et al. 2011; Rawls & Turnquist 2010; Rawls & Turnquist 2011; Rawls & Turnquist 2012; Sherali et al. 1991; Wilhelm & Srinivasa 1996; Yushimito et al. 2012; Zhang et al. 2013
Transportation (Relief distribution & Casualty transportation)	30	Adivar & Mert 2010; Balcik et al. 2008; Barbarosoğlu & Arda 2004; Barbarosoğlu et al. 2002; Berkoune et al. 2012; Campbell et al. 2008; Chen et al. 2011; Chern et al. 2010; Gu 2011; Haghani & Oh 1996; Hu 2011; Huang et al. 2012; Jotshi et al. 2009; Lin et al. 2011; Najafi et al. 2013; Özdamar 2011; Özdamar et al. 2004; Özdamar & Demir 2012; Özdamar & Yi 2008; Shen et al. 2009; Sheu 2007a; Suzuki 2012; Tzeng et al. 2007; Vitoriano et al. 2009; Vitoriano et al. 2011; Wohlgemuthscha et al. 2012; Yi & Kumar 2007; Yi & Özdamar 2004; Yuan & Wang 2009; Zhang et al. 2013
Location and Transportation	8	Afshar & Haghani 2012; Mete & Zabinsky 2010; Naji-Azimi et al. 2012; Nolz et al. 2010; Nolz et al. 2011; Ukkusuri & Yushimito 2008; Yi & Özdamar 2007;Zografos & Androutsopoulos 2008.
Other important topics	16	Altay 2012; Duque & Sörensen 2011; Falasca & Zobel 2012; Feng & Wang 2003; Huang et al. 2013; Lodree Jr et al. 2012; Minciardi et al. 2007; Minciardi et al. 2009; Rottkemper et al. 2012; Rottkemper et al. 2011; Turner et al. 2012; Viswanath & Peeta 2003; Xu et al. 2010; Yan & Shih 2009; Yan & Shih 2007.

Table 2: Location and network design problems in relief distribution

	Article	Data Modeling	Problem characteristics							Resolution Method	Tested over
			Objective	Periods	Commodity	Cap. Limits	Sourcing	RA	Main Obj.		
Post event context	Horner and Downs, 2010	Static	Single	Single	Single	Yes	Single	Yes	1	Exact	CS
	Horner and Downs, 2007	Static	Multi	Single	Single	No	Single	No	1	Exact	CS
	Iakovou et al., 1996	Static	Single	Single	Multi	Yes	Multi	Yes	1	Heuristic	CS
	Jia et al, 2007a	Static	Single	Single	Single	No	Multi	No	2	Exact	CS
	Jia et al., 2007b	Static	Single	Single	Single	No	Multi	No	2	Heuristic	CS
	Lee et al., 2009a	Static	Single	Single	Single	Yes	Single	Yes	2	Exact	CS
	Lee et al. , 2009b	Static	Single	Single	Single	Yes	Single	Yes	2	Exact	CS
	Lin et al., 2012	Static	Single	Multi	Multi	Yes	Single	Yes	2 3 4	Heuristic	CS
	Murali et al., 2012	Stochastic	Single	Single	Single	Yes	Multi	Yes	2	Heuristic	CS
	Zhang et al., 2012	Static	Single	Single	Multi	Yes	Multi	Yes	1	Heuristic	Acad.
Pre event context	Balcik and Beamon, 2008	Stochastic	Single	Single	Multi	Yes	Multi	Yes	2	Exact	Acad.
	Bozorgi-Amiri et al., 2012	Stochastic	Single	Single	Multi	Yes	Multi	Yes	1	Heuristic	Acad.
	Campbell and Jones, 2011	Stochastic	Single	Single	Single	No	Single	Yes	1	Exact	Acad.
	Chang et al., 2007	Stochastic	Single	Single	Multi	Yes	Multi	Yes	3	Heuristic	CS
	Davis et al., 2013	Stochastic	Single	Single	Single	Yes	Multi	Yes	1	Exact	CS
	Drezner T. 2004	Static	Multi	Single	Single	No	Multi	No	2	Exact	CS
	Drezner et al., 2005	Static	Multi	Single	Single	No	Multi	No	2	Heuristic	CS
	Görmez et al., 2011	Static	Multi	Single	Single	Yes	Multi	Yes	1 2	Exact	CS
	Hong et al., 2013	Static	Single	Single	Single	No	Single	Yes	1	Exact	CS
	Nagurney et al., 2011	Stochastic	Single	Single	Single	Yes	Multi	Yes	1	Exact	Acad.
	Rawls and Turnquist, 2010	Stochastic	Single	Single	Multi	Yes	Multi	Yes	1 2	Heuristic	Both
	Rawls and Turnquist, 2011	Stochastic	Single	Single	Multi	Yes	Multi	Yes	1 2	Exact	CS
	Rawls and Turnquist, 2012	Stochastic	Single	Multi	Multi	Yes	Multi	Yes	1 2	Exact	CS
	Wilhelm and Srinivasa, 1996	Stochastic	Single	Multi	Single	Yes	Single	Yes	1	Heuristic	CS
	Yushimito et al., 2012	Static	Single	Single	Single	No	Single	No	4	Heuristic	Acad.
	Zhang et al., 2013	Static	Multi	Single	Single	No	Single	Yes	2	Heuristic	Acad.
	Kongsomsaksakul et al., 2005*	Static	Single	Single	Single	Yes	Multi	Yes	3	Heuristic	CS
	Li et al., 2010*	Stochastic	Single	Single	Multi	Yes	Multi	Yes	1	Exact	CS
	Sherali et al., 1991*	Static	Single	S&M	Single	Yes	Multi	Yes	3	Ex. / Heu.	CS

*Shelter location problems

Table 3: Transportation problems in relief distribution

	Authors	Data Modeling	Problem characteristics								Resolution Method	Tested over
			Obj.	Periods	Commodity	Depots	Capacity Limits	Fleet Comp.	Tr. Mode	Main Obj.		
Relief Distribution	Adivar and Mert, 2010	Fuzzy	Multi	Multi	Multi	Multi	Weight	Hetero.	Multi	1 5	Exact	CS
	Balcik et al., 2008	Dynamic	Single	Multi	Multi	Single	Vol./Time/Fleet	Hetero.	Ground	1 2	Exact	Acad.
	Barbarosoğlu et al., 2004	Stochastic	Single	Single	Multi	Multi	Units	Hetero.	Multi	1	Exact	CS
	Berkoune et al., 2012	Static	Single	Single	Multi	Multi	W./Vol./Time/Fleet	Hetero.	Ground	3	Heur.	Acad.
	Campbell et al., 2008	Static	Single	Single	Single	Single	No	Homo.	Ground	3	Heur.	Acad.
	Chen et al., 2011	Static	Single	Single	Single	Multi	Units	Homo.	Ground	3	Exact	CS
	Gu, 2011	Sta.-Fuz.	Single	Single	Single-Multi	Multi	Units±	Homo.	Ground	2	Exact	Acad.
	Haghani et al., 1996	Static	Single	Multi	Multi	Multi	Units/Fleet	Hetero.	Multi	1	Heur.	Acad.
	Hu, 2011	Static	Multi	Single	Multi	Single	No	Hetero.	Multi	1	Exact	Acad.
	Huang et al., 2012	Static	Single	Single	Single	Single	Units	Homo.	Ground	3 2 4	Heur.	Acad.
	Lin et al., 2011	Static	S&M	Multi	Multi	Single	W./Vol./Time/Fleet	Homo.	Ground	2 3 4	Heur.	Acad.
	Özdamar et al., 2004	Dynamic	Single	Multi	Multi	Multi	Weight/Fleet	Hetero.	Multi	2	Heur.	CS
	Shen et al., 2009	Stochastic	Single	Single	Single	Single	Units/Fleet	Hetero.	Ground	2 3	Heur.	Acad.
	Sheu, 2007a	Dynamic	Multi	Multi	Multi	Multi	Units/Fleet	Hetero.	Ground	2 1	Exact	CS
	Suzuki 2012	Static	Single	Single	Single	Single	Weight/Fuel/Time	Hetero.	Ground	2 4	Exact	Acad.
	Tzeng et al,2007	Dynamic	Multi	Multi	Multi	Multi	Volume	Homo.	Ground	1 3 4	Exact/Sim.	Acad.
	Vitoriano et al., 2011	Stochastic	Multi	Single	Single	Multi	Units/Fleet/Budget	Hetero.	Ground	1 3 4 5	Exact	CS
	Vitoriano et al., 2009	Stochastic	Multi	Single	Single	Multi	Units/Budget	Hetero.	Ground	1 3 4 5	Exact	CS
	Wohlgemuth et al., 2012	Dynamic	Single	Multi	Single	Single	Units	Homo.	Ground	3 1	Heuristic	Acad.
	Yuan and Wang, 2009	Static	S.&M.	Multi	Single	Single	No	Homo.	Ground	3 5	Heur./Sim.	Acad.
	Zhang et al. 2013	Static	Single	Multi	Single	Single	No	Homo.	Ground	3	Heuristic	Acad.
	Jotshi et al., 2009*	Static	Multi	Single	Single	Multi	Units/Fleet	Homo.	Ground	2	Heur./Sim.	CS
Dist. and Evacuation	Barbarosoğlu et al., 2002	Static	Multi	Single	Multi	Multi	Weight/Fleet/Time	Hetero.	Air	1	Heur.	Acad.
	Chern et al., 2010	Dynamic	Multi	Multi	Multi	Multi	Units/Fleet/Fuel	Hetero.	Multi	2 3 1	Heur.	Acad.
	Najafi et al., 2013	Stochastic	Multi	Multi	Multi	Multi	W./Vol./Units/Fleet	Hetero.	Multi	2 1	Exact	CS
	Özdamar, 2012	Static	Single	Single	Multi	Multi	Fleet/Units	Hetero.	Ground	3	Heur.	Acad.
	Özdamar and Yi., 2008	Static	Single	Multi	Multi	Multi	Units/Fleet	Hetero.	Ground	3	Heur.	Acad.
	Özdamar, 2011	Static	Single	Single	Multi	Multi	Weight/Time/Units	Homo.	Air	3	Heur.	Acad.
	Yi and Kumar, 2007	Static	Single	Multi	Multi	Multi	Weight/Fleet	Hetero.	Ground	2	Heur.	Acad.
	Yi and Ozdamar, 2004	Fuzzy	Single	Multi	Multi	Multi	Weight/Fleet	Hetero.	Multi	2	Exact	CS

Table 4: Combined Location-Transportation problems in relief distribution

Authors	Data Modeling	Problem characteristics										Resolution Method	Tested over
		Objective	Periods	Commodity	Site capacity	R.A	Depots and Sourcing	Tr. Capacity Limits	Fleet Comp.	Tr. Mode	Main Obj.		
Afshar and Hagani, 2012	Dynamic	Single	Multi	Multi	Yes	Yes	Multi	Units/Fleet/Weight	Hetero.	Multi	2	Exact	Acad
Mete and Zabinsky, 2010	Stochastic	Single	Single	Multi	Yes	Yes	Multi	Units/Fleet	Hetero.	Ground	1 3	Exact	CS
Naji-Azimi et al., 2012	Static	Single	Single	Multi	No	No	Single	Weight/Fleet	Hetero.	Ground	3	Heuristic	Acad
Nolz et al.,2010	Static	Multi	Single	Single	Yes	No	Single	Units/Fleet	Hetero.	Multi	2 3	Heuristic	CS
Nolz et al., 2011	Static	Multi	Single	Single	Yes	No	Single	Units/Fleet	Homo.	Ground	5 3	Heuristic	CS
Ukkusuri and Yushimito, 2008	Static-Stoch.	Single	Single	Single	No	No	Single	Budget/Fleet	Homo.	Ground	1	Exact	Acad
Yi, W. and Özdamar, L., 2007	Dynamic	Single	Multi	Multi	Yes	Yes	Multi	Weight	Hetero.	Ground	2	Heurisitic	CS
Zografos and Androutsopoulos, 2008	Static	Multi	Single	Single	Yes	Yes	Single	Units/Fleet	Homo.	Ground	3 5	Heuristic	CS