A COMPREHENSIVE LITERATURE REVIEW FOR HUMANITARIAN RELIEF LOGISTICS IN DISASTER OPERATIONS MANAGEMENT

Alev Taskin GUMUS1 Erkan CELIK2

ABSTRACT
Based on social and economic factors, humanitarian relief logistics (HRL) in disaster operations management (DOM) issues have attracted attention among both academia and practitioners. Hence, a comprehensive literature review of recent and state of the art papers is vital to draw a framework of the past, and to shed light on future directions. In this paper, a state of the art literature review is presented for optimization and decision science to HRL activities in DOM. A total of 220 papers published between January 2007 and May 2015 are selected and reviewed. In particular, the facility location, inventory management, relief distribution planning, debris cleaning and recovery operations, decision support systems, and other operations in accordance with the relevant HRL activities in DOM are investigated. Finally, a list of research gap and further research are identified to clarify and to suggest future research opportunities.

Keywords: humanitarian relief logistics, disaster operations management, mathematical models.

AFET OPERASYON YÖNETİMİNDE İNSANİ YARDIM LOJİSTİĞİ İÇİN KAPSAMLI BİR LİTERATÜR İNCELEMESİ

ÖZ

Anahtar Kelimeler: insani yardım lojistiği, afet operasyon yönetimi, matematiksel modeller

1 Assoc. Prof. Dr., Department of Industrial Engineering, Yildiz Technical University, 34349 Besiktas, İstanbul, Turkey
2 Asst. Prof. Dr., Department of Industrial Engineering, Tunceli University, 62000, Tunceli, Turkey
1. INTRODUCTION
The main objective of the HRL in DOM is to acquire and deliver the requested supplies and services, at the places and times they are needed, while ensuring best value for money. These critical supplies are vital in post disaster activities for survival, such as food, water, temporary shelter and medicine, among others (IFRC, 2013). It directly focuses on helping the sufferers and injured people on disaster areas. According to the records of The Centre for Research on the Epidemiology of Disasters (CRED-EMDAT), between 2007 and 2015; 9,835 disasters have been registered. The CRED estimates 2,397.6 billion dollars in economic damage from these events, 1,496,804 casualties, and 2.820 billion of affected people. Efficient and effective preparedness and response planning can significantly decrease the social, economic and environmental impact of disasters. Hence, operation research and management science (OR/MS) perspectives and techniques for HRL in DOM are very suitable (Altay and Green, 2006) and they can play a great role for preparing the society and reducing the negative impact of disasters (Hoyos et al. 2015). In this paper, we surveys the recent body of literature to improve the decision making process of four phase (mitigation, preparedness, response and recovery) for HRL in DOM and includes stochastic parameters, objective functions and solution approaches. The rest of this document is organized as follows: some earlier review papers are analyzed in Section 2. The used research methodologies are explained in Section 3. Detailed analyses and classifications for mathematical models, solution approaches and stochastic parameters of reviewed papers are discussed in Section 4. Section 5 reveals the results of reviewing process. Finally, Section 6 contains the conclusion and future research.

2. LITERATURE REVIEW
Some review studies should be mentioned here to explain the need for this study. The scope of the earlier review papers are illustrated in Table 1. In the light of Table 1, the first literature review was conducted by Altay and Green (2006) in context of OR/MS. They analyzed 109 articles considering all kind of disasters and OR/MS. According to their results, a better understanding of the inputs and characteristics of different events as well as the development of new solution methodologies were needed. They also proposed more research on multi-agency structures in order to facilitate the coordination and communications are needed. Galindo and Batta (2013) presented a review as a recent development in OR/MS by considering the same methodologies of Altay and Green (2006)’s survey. According to their conclusion, there has not been a significant change in the methodology percentages since 2006. They also pointed out the lack of research developed in conjunction with humanitarian organizations, the lack of papers for the recovery phase and the need to better understand and analyze the inputs and assumptions in the models. Whybark (2007) provided a review for inventory in disaster relief management. The characteristics of disaster relief inventory in areas of acquisition, storage and distribution are described. Kovacs and Spens (2007) focused on logistics and supply chain management (SCM) in disasters by considering 98 articles. They proposed more research papers in the different stages of disasters. The next studies can investigate the infrastructure, uncertainty in demand, supply and response time and
the need of dynamic models in this context. Natarajarathinam et al. (2009) presented a review for SCM in times of crisis. They analyzed 118 papers that are published both SCM and operations research and management science journals. de la Torre et al. (2012) presented a review on vehicle routing problems in disaster-affected regions. They have classified their review with respect to allocation, needs assessment, uncertainty and their different objectives. Caunhye et al. (2012) presented a review on optimization models in emergency logistics with respect to FL problem, relief distribution and casualty transportation problem. They provide detailed information about model types, decisions, objectives and constraints. They proposed cross-operation models including the possibility of inter-facility stock transfer and casualty transportation combining transportation time, injury seriousness and on-field treatment and appropriate solution algorithms for future research. Ortúñ et al. (2013) presented a literature review on the decision aid models and systems applied to humanitarian logistics (HL) in this context. Holguín-Veras et al. (2013) suggested the use of social cost as objective function for post-disaster HL models. Liberatore et al. (2013) analyzed uncertainty in HL based on 27 papers. Demand, demand location, affected areas, supply, and transportation network are determined as five stochastic parameters considering uncertainty in HL. In addition to Liberatore et al. (2013)’s review, Hoyos et al. (2015) presented a bibliographic review on OR techniques with stochastic components in DOM. They analyzed the stochastic components for each paper and the methodologies used to solve or model them. Leiras et al. (2014) have analyzed 228 papers that were published in the HL with respect to predetermined ten criteria. Anaya-Arenas et al. (2014) discuss location and transportation models and categorize them according to their objectives, constraints and solution methods. Zheng et al. (2015) provided an overview of evolutionary algorithms for disaster relief operations. These evolutionary algorithms are genetic algorithms (GA), particle swarm optimization (PSO), ant colony optimization (ACO), biogeography-based optimization, artificial immune system, simulated annealing (SA), tabu search (TS), harmony search (HS), variable neighborhood search (VNS) and hybrid metaheuristic algorithms. They stated that usage of evolutionary computation in disaster relief operations for future studies is tied to both the increasing difficulty of practical problems and the advances of evolutionary algorithms themselves. Gul and Guneri (2015) analyzed simulation models for hospital emergency department in disaster times. They concluded that papers about disaster times are too few. Özdamar and Ertem (2015) reviewed the logistics models developed for the response and recovery planning phases in terms of their modeling features and formulation structures. The main aim of our review is to present a detail review by considering stochastic parameters (in addition to Liberatore (2013) and Hoyos et al. (2015)’s reviews), objectives and solution approaches (in addition to Zheng et al. (2015) and Özdamar and Ertem (2015)’s review) that are applied in HRL. The last line of the Table 1 presents the role of our paper in covering the presented gap of the literature.
Table 1. Characteristics of earlier review studies

<table>
<thead>
<tr>
<th>Paper</th>
<th>Scope</th>
<th>Year</th>
<th>No. of papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whybark (2007)</td>
<td>Relief inventory in disaster management</td>
<td>Up to 2005</td>
<td>19</td>
</tr>
<tr>
<td>de la Torre et al. (2012)</td>
<td>Routing problem in disaster relief</td>
<td>Up to 2011</td>
<td>58</td>
</tr>
<tr>
<td>Caunhye et al. (2012)</td>
<td>Optimization models in emergency logistics</td>
<td>2001-2011</td>
<td>74</td>
</tr>
<tr>
<td>Ortuño et al. (2013)</td>
<td>Decision aid models and systems for humanitarian logistics</td>
<td>Up to 2012</td>
<td>100</td>
</tr>
<tr>
<td>Liberatore et al. (2013)</td>
<td>Uncertainty in HL</td>
<td>Up to 2012</td>
<td>27</td>
</tr>
<tr>
<td>Holguín-Veras et al. (2013)</td>
<td>Objective function for post-disaster HL models</td>
<td>Up to 2012</td>
<td>-</td>
</tr>
<tr>
<td>Leiras et al. (2014)</td>
<td>HL with respect to predefined ten criteria</td>
<td>Up to 2012</td>
<td>228</td>
</tr>
<tr>
<td>Anaya-Arenas et al. (2014)</td>
<td>Relief distribution networks in response to disasters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galindo and Batta (2014)</td>
<td>OR/MS research in DOM</td>
<td>2005-2010</td>
<td>155</td>
</tr>
<tr>
<td>Zheng et al. (2015)</td>
<td>Evolutionary algorithm in disaster relief</td>
<td>Up to 2014</td>
<td>121</td>
</tr>
<tr>
<td>Gul and Guneri (2015)</td>
<td>Simulation model in emergency department in normal and disaster times</td>
<td>up to 2014</td>
<td>-</td>
</tr>
<tr>
<td>Özdamar and Ertem (2015)</td>
<td>Response and recovery planning phases</td>
<td>up to 2014</td>
<td>-</td>
</tr>
<tr>
<td>Hoyos et al. (2015)</td>
<td>Stochastic components in DOM</td>
<td>2006-2012</td>
<td>101</td>
</tr>
<tr>
<td>Our Study</td>
<td>Uncertainty, objectives, and solution approaches in HRL</td>
<td>January 2007-May 2015</td>
<td>220</td>
</tr>
</tbody>
</table>

3. RESEARCH METHODOLOGY
In this literature review, we utilized paper searching and collection, descriptive analysis, classification selection or analyzing, and material evaluation the research methodology of the papers (Govindan et al., 2015).

3.1. Paper Searching and Collection
The process of the literature review is detailed in this part. The study is conducted from September 2014 to May 2015 covering the accepted and published (available online) papers in scientific journals from January 2007 to May 2015. The literature review considers mostly published journal papers in Elsevier, Taylor and Francis Online, Wiley, Springerlink, IEEE Xplore and Google-scholar search engine (www.scholar.google.com) with some keywords. Disaster logistics, disaster relief
logistics, emergency relief, emergency relief logistics, HL, humanitarian relief are combined with optimization, mathematical models which have been used and the references of every paper have been searched. For example, “Disaster logistics and optimization” are searched in above mentioned database.

3.2. Descriptive Analysis
The distribution of journals in which the selected papers are published indicates the desires of different journals for HRL in DOM. This study aims to analyze 220 scientific papers published between January 2007 and May 2015 as illustrated in Figure 1. The publications and distribution of the journals are presented in Table 2 and Figure2.

![Figure 1: Number of papers based on different journals (220 papers: January 2007–May 2015)](image)

Table 2. Distribution of literature based on the source of publication

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-Economic Planning Sciences</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation Research Part E</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>International Journal of Production Economics</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Computers &amp; Operations Research</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>OR Spectrum European Journal of Operational Research</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Number of papers based on different journals (220 papers: January 2007–May 2015)
From the 220 articles reviewed, 87 use mathematical models and solution approach, 80 apply mathematical models, 10 simulation, 6 multi criteria decision making (MCDM) approaches, 5 DSS, and 4 conceptual papers, 4 pure solution approaches, 2 forecasting, 2 fuzzy logic, 16 literature review, 2 mathematical models and simulation, 2 survey and 1 case study, as shown in Figure 3 and Figure 4.
Among them, 77 are considered part of the response phase, 74 of the preparedness and response stages, 35 of the preparedness stage and 7 recovery stage, 5 of the mitigation and response stages, 4 of the response and recovery stages, 1 of the mitigation and preparedness stages, 1 of the mitigation, preparedness and response stages, 1 of the preparedness, response and recovery stages, as shown in Figure 5. 81 papers are proposed for pre-disaster, 45 of the post-disaster, and 81 of the both pre-disaster and post-disaster. According to the Figure 6, the most of the studies used empirical data. On the other hand, USA, Turkey, China and Taiwan are the most dominant countries for presenting case study.

![Figure 5: Classification of articles by phase of disaster](image)

![Figure 6: Distribution of case study for country](image)

### 3.3. Classification Selection or Analyzing

The main scopes of this study and major topics of analysis including detailed classifications contains problem type, research technique, modeling approach, exact/approximate solution, solution method, single/multi objective, objective(s), data type, stochastic variables, disaster type, disaster phase, empirical/case study, and country. After this categorization, the literature is classified into five main categories: (1) FL, (2) IM, (3) RDP, (4) DCRO, (5) DSS, and (6) other operations. Each section is detailed based on mathematical model and solution procedure used.

#### 1.1. Material Evaluation

The papers were reviewed according to the classification above mentioned. The categorization process and cross checking was applied to obtain rigor in validity.
Besides, using Microsoft Excel spreadsheet is supportive in minimizing error, and evaluating different aspects of analyses. After that, a sample of papers was read, analyzed and classified by both authors to compare assignment decisions and address inter-coder agreement.

2. MATHEMATICAL MODELS
The mathematical models for HRL in DOM are classified in five problems as FL, IM, RDP, DCRO, DSS, and other operations.

2.1. Facility Location
FL decisions play a critical role (Melo et al., 2009) and affect directly the performance of relief operations (Balcik and Beamon, 2008). FL problem for HRL in DOM is studied with allocation, prepositioning, routing and distribution of relief items. In this section, location models, location and allocation (LA) models, and LA models with prepositioning are reviewed in detail.

2.1.1. Location Models
The only location-alone models are first published by Toregas et al. (1971), Psaraftis et al. (1986), Iakovou et al. (1996) for emergency management. Jia et al. (2007a) proposed a general FL model as well as p-median and p-center. It is aimed to minimize unmet demands and loss of life for different large-scale emergencies. Jia et al. (2007b) also proposed maximal covering problem with multiple facility quantity of coverage and quality of coverage requirements for determining FL of medical supplies in response to large-scale emergencies. Three heuristics are developed to solve the location problem: a GA heuristic, locate-allocate heuristic, and Lagrangean relaxation heuristic. Balcik and Beamon (2008) presented a variant of the maximal covering location model for minimizing the expected number of casualties and unmet demand for transfer population. Doerner et al. (2009) proposed nondominated sorting GA for multi-objective (MO) model of minisum facility and maximal covering location criterion problem. These objectives are minimization of tsunami risk, determining the shortest distance and minimization of the total costs. Huang et al. (2010) proposed integer linear programming for large-scale emergency. Horner and Downs (2010) presented GIS-based spatial model taking into account capacitated FL problem for hurricane disaster relief distribution strategies. Nolz et al. (2010) presented a MO covering tour problem which considers risk, FL and distance criteria for delivering disaster relief supplies. Five different risk measures are applied. A memetic algorithm based on the nondominated sorting GA is also proposed for generating a set of potentially Pareto-optimal solutions. Görmez et al. (2011) analyzed the trade-offs between minimizing the average-weighted distance and opening new facilities under various disaster scenarios and investigate the solutions for several models extensions. Verma and Gaukler (2011) proposed TSSP for minimizing distance of positioning disaster response facilities for large scale emergencies. Nolz et al. (2011) developed a MO optimization problem and memetic algorithm for covering tour problem. They aimed to minimize both risk and travel time and maximize the coverage of the population. Chi et al. (2011) presented a GA for a hierarchical FL model. It is aimed to minimize the total open and transportation
cost. Widener and Horner (2011) and Yushimito et al. (2012) solved p-median problem for minimizing travel cost and social cost, respectively. Ecerkale (2012) applied fuzzy c-means clustering and PSO to determine Turkish Red Crescent aid depot locations. Fuzzy c-means clustering analysis method clustered 54 risky areas with respect to their geographical coordinates. PSO algorithm has been used for each cluster to minimize the transportation coefficient. Naji-Azimi et al. (2012) proposed Multi-start heuristic for satellite distribution in disaster relief. Eiselt and Marianov (2012) developed a mathematical model for mobile phone tower locations that aims to maximize service coverage and minimize the loss of communications if a natural disaster happens. Lu and Sheu (2013) proposed a SA based approach for robust vertex p-center problem. They aimed to minimize worst-case deviation from the optimal solution in maximum travel time that is taken into consideration as uncertain. The results of the SA based approach are compared with enumeration approach. In addition, the result of robust vertex p-center problem is also compared with two-stage stochastic programming (TSSP). Lu et al. (2013) also proposed SA based approach for robust weighted vertex p-center problem. Kelle et al. (2014) proposed L-shaped algorithm for p-median reliable regret problem to decide alternatives between expected cost minimization and worst case scenario in emergency supply. They suggested a compromising decision criterion and applied it for hurricane supply of commodities. Akgün et al. (2015) developed an optimization model that minimizes the risk that a demand point may be exposed to because it is not supported by the located facilities. Kilči et al. (2015) proposed a mixed integer linear programming (MILP) for selecting the location of temporary shelter sites. They presented a case study of Kartal district for validation of possible earthquake in Istanbul. The proposed model is also presented using data from 2011 Van, Ercis earthquake.

3.3.1. Location and Allocation Models

LA models aims to optimize the location of distribution centers (warehouses) and allocating demand point to the centers for preparedness to disaster. Some papers proposed different mathematical models as TSSP (Chang et al. (2007), Güneş and Salman (2007), Mete and Zabinsky (2007), Salmeron and Apte (2010), Döyen et al. (2012), Verma et al. (2013), Li et al. (2011)), risk averse TSSP (Noyan (2012), Hong et al. (2015)), robust optimization (Bozorgi-Amiri et al. (2011), Jabbarzadeh et al. (2014)), MIP (Shui et al. (2008), Salmeron and Apte (2010), Bozorgi-Amiri et al. (2011), Döyen et al. (2012), Abounacer et al. (2014), Falasca and Zobel (2012), Paul and Hariharan (2012), Jeong et al. (2013), Hu et al. (2014)), dynamic allocation model (Rawls and Turnquist (2012)), fuzzy model (Cheng et al. (2013)), IP (Falasca and Zobel (2012)), MINLP (Bozorgi-Amiri et al. (2011), Mirzapour et al. (2013)), goal programming (GP) (Barzinpour and Esmaeili (2014), Güneş and Salman (2007). Chang et al. (2007) applied real data for the flood emergency logistics preparation by using sample average approximation (SAA). Güneş and Salman (2007) and Mete and Zabinsky (2007) incorporated the selection of the warehouse locations for medical supplies and the inventory levels for every type of medical supplies in the favorable warehouses. Gong and Batta (2007) first allocated the
correct number of ambulances to each cluster at the beginning of the rescue process. Then, they analyzed the reallocation of ambulances for providing service to new clusters and fully utilizing ambulances. Barzinpour and Esmaeili (2014) developed GP formulation for minimizing the weighted sum of travel times, the maximum time for each commodity to reach a demand point, the risk of selected locations and unsatisfied demand. Salman and Yücel (2014) aimed to maximize the expected demand coverage within a specified distance overall possible network realization when road link is reliable. Charles and Lauras (2011) proposed a business process models approach that helps in understanding, analyzing, evaluating and then developing the formal expression of a humanitarian supply chains. Bozorgi-Amiri et al. (2011) developed a modified PSO algorithm for LA problem. Döyen et al. (2012) and Li et al. (2012) solved their model by using Lagrangean relaxation method. Murali et al. (2012) presented locate-allocate heuristic for capacitated FL in order to maximize coverage, taking into account a distance-dependent coverage function and demand uncertainty. Lin et al. (2012) proposed a two-phase heuristic approach for the location of temporary depots around the disaster-affected area, along with the required vehicles and resources, to improve logistical efficiency. It is aimed to minimize the total operational cost of the disaster. Abounacer et al. (2014) proposed an exact solution approach denoted adaptive epsilon-constraint method for three conflicting objectives. Chou et al. (2014) applied the biological based GA for allocating disaster refuge site staff and planning relief supply distribution. They compared the proposed algorithm with immune algorithms and GAs in terms of effectiveness. Salman and Gül (2014) proposed a multi-period MIP for dynamic casualty transportation model for determining the location and size of emergency service facilities to be established after a disaster to cope with the demand surge. Zhan and Liu (2014) and Zhan et al. (2014) applied Bayesian update information for resource allocation for typhoons response plan. Zhan and Liu (2014) proposed a novel method of relief demand updating, and devise a lost function as a function of time delay. They also developed a relief allocation model for determining the optimal delay in response to typhoon disaster. Zhan et al. (2014) developed a MO optimization model based on disaster scenario information updates. They aimed to minimize total time, total unmet demands, and total costs. Barzinpour et al. (2014) and Esmaeili and Barzinpour (2014) proposed a GA for LA problem in disaster relief logistics. The results of the GA are compared with SA and mathematical model solutions. Jabbarzadeh et al. (2014) proposed a robust network design model for blood FL and allocation problem during and after disasters. Noyan (2012) and Hong et al. (2015) proposed risk-averse TSSP for LA model to disaster management. While Noyan (2012) developed Bender-decomposition based algorithms, Caunhye et al. (2015) developed a LA model that locates alternative care facilities and allocate casualty allocation plan for catastrophic radiological events that aims to minimize the total weighted transportation time of casualties. Hu et al. (2014) developed a novel MILP for multi-step evacuation and temporary resettlement under minimization of panic-induced psychological penalty cost, psychological intervention cost, and costs associated with transportation and building shelters. Rath et al. (2015) proposed epsilon constraint method for maximizing demand coverage and minimizing the total cost objectives. Huang et al.
(2015) formulated three objective functions for HL as lifesaving utility, delay cost and fairness. They designed efficient variational inequality algorithm for MO optimization model that combines resource allocation with emergency distribution.

3.3.2. Location and Allocation Models with Prepositioning

Preparation in anticipation of a disaster involves FL and resource allocation with prepositioning of facility and/or supply. The most used approach for this problem is TSSP (Rawls and Turnquist (2010), Salmeron and Apte (2010), Verma and Gaukler (2011a), Rawls and Turnquist (2011), Rawls and Turnquist (2012), Lodree et al. (2012), Davis et al. (2013), Klibi et al. (2013), Verma and Gaukler (2014), Renkli and Duran (2015)). Ukkusuri and Yushimito (2008) applied the most reliable path and an IP model to find the optimal location of supplies. Rawls and Turnquist (2010) presented a TSSP and applied Lagrangian L-shaped heuristic method to determine the location and quantities of various types of emergency supplies to be prepositioned under uncertainty. Campbell and Jones (2011) consider prepositioning problem to determine the optimal stocking quantity and the total expected costs associated with delivering to a demand point from a supply point for preparation to a disaster. Duran et al. (2011) developed a MIP to evaluate the effect of relief items prepositioning on average emergency response time to provide relief aid to people affected by natural disasters. Rawls and Turnquist (2011) aimed to minimize the expected costs over all scenarios resulting from the selection of the locations and facility sizes, the commodity acquisition and the stocking decisions, the shipments of the supplies to the demand points, unmet demand penalties, and holding costs for unused material. Bozkurt and Duran (2012) analyzed the trends of natural disasters to determine optimal locations for prepositioning warehouses. Hong et al. (2012) proposed a TSSP model for a pre-disaster relief network design to determine the size and the location of the response facilities and the inventory levels of relief supplies at each facility. Galindo and Batta (2013) presented a capacitated FL programming model which takes into account probability of destruction for pre-positioning of supplies for preparing a hurricane. Irohara et al. (2013) proposed a dual-ascent approach for solving tri-level programming model in disaster preparedness planning that allows for anticipation of the cost of recovery post-disaster at the preparedness stage. Opit et al. (2013) developed a MILP model for prepositioning relief commodity for minimizing lower bound of the proportion of unsatisfied relief demand. Davis et al. (2013) presented a two-stage recourse programming model for minimizing the prepositioning, redistribution, distribution, supply shortage and prepositioned supply loss cost. Klibi et al. (2013) proposed a TSSP approach for pre-positioning emergency supplies to make decisions on location, number, capacity of the facilities, and inventories level. They generated scenarios using the Monte Carlo procedure. The proposed model is solved using a SAA. Chakravarty (2014) aimed to define optimal mix of prepositioning of inventory, and rapid response through real-time delivery. Kunz et al. (2014) proposed a system dynamic models approach to compare three scenarios as no preparedness activity, pre-positioning of inventory, and investment in intangible preparedness activities. They also extend analysis mixed scenarios, consisting of both prepositioning inventory and investing in disaster management capabilities, under the constraint of different levels of yearly
preparedness costs. Verma and Gaukler (2014) proposed deterministic and stochastic location models for pre-positioning disaster response facilities. They also applied a heuristic solution based Benders Decomposition algorithm for TSSP model that considers the damage intensity as a random variable. Yang et al. (2014) proposed data envelopment analysis (DEA) for allocation of reserves relief supplies by considering the risk, cost, equity and effectiveness attributes. Renkli and Duran (2015) proposed an uncapacitated FL and allocation with chance constrained problem for pre-positioning disaster response facilities. They aimed to minimize the expected average distance and travelled time while the infrastructure is taken into probabilistic constraints. Hong et al. (2015) developed chance-constrained models. Roh et al. (2015) used MCDM approach for location problems in the context of HRL. AHP and fuzzy TOPSIS approach is applied for evaluating prepositioned warehouse location.

3.4. Inventory Management
Disaster inventory is determined as social inventory (Whybark 2004, 2007) which differs from commercial inventory and needs quick assessment (Sheu, 2007). Whybark (2007) described the characteristics of acquisition, storage and distribution of disaster relief. They also presented some of the important differences from enterprise inventories in the areas of acquisition, storage and distribution detailed comparison. In this paper, we reviewed relief inventory with respect to procurement, inventory control model and forecasting techniques.

3.4.1. Procurement
Procurement of inventory for HRL is fairly expensive because of the quick delivery (Sheu, 2007) that is the main concern of relief supplies. Hence, some papers are proposed for procurement operation in HRL (McCoy and Brandeau (2011), Ertem and Buyurgan (2013), Ertem ve Buyurgan (2011), Ertem et al. (2010), Ertem et al. (2012), Trestrail et al. (2009), Bagchi et al. (2011), Sheu and Pan (2014), Liang et al. (2012), Falasca and Zobel (2011), Balcik and Ak (2014). Trestrail et al. (2009) proposed a two stage MIP for improving bid pricing of HL. The objective function minimizes both food commodity and ocean carrier transportation costs. Ertem et al. (2010) developed a holistic framework by combining the announcement construction, bid construction and bid evaluation phases for procurement operation of disaster relief. Bagchi et al. (2011) aimed to determine the optimal auction mechanism to deter gaming and minimizing awarded bid prices. Falasca and Zobel (2011) proposed a two-stage stochastic decision model with recourse for procurement in HR supply chains, and compared its effectiveness on an illustrative example with respect to a standard solution approach. Ertem and Buyurgan (2011) used IP for an auction based framework for a single coordinating platform in disaster relief logistics. McCoy and Brandeau (2011) modelled a single-item inventory system with instantaneous replenishment for efficient stockpiling and shipping policies in HR. The model finds the optimal number of relief items to stockpile as well as the shipment policy for such items, given a fixed total budget for combined stockpiling and shipping costs. Ertem et al. (2012) presented a GA, SA and IP model for bid construction phase of procurement auction. The GA, SA, and
IP are compared using three performance metrics. The SA and IP models are selected for their study due to steady performance compared to the GA. Liang et al. (2012) introduced the option contract mechanism into relief material SCM for considering as a one buyer and one supplier supply chain. Ertem and Buyurgan (2013) proposed an auction-based procurement method that is to state and promote the coordination among humanitarian organizations and suppliers during response and recovery operations. Balcik and Ak (2014) proposed a TSSP model to supplier selection for framework agreements in HR. The proposed model is applied to select a water supplier in Turkish Red Crescent. They also proposed future studies for developing new models that service-based objective function and budget constraints are considered. Also, the future studies should consider multi product for budget constraint. Sheu and Pan (2015) proposed a two-stage relief supplier clustering mechanism for time-varying multi-source relief supplier selection, and stochastic dynamic programming (DP) model to determine a multi-source relief supply for relief supply collaboration that minimizes the impact of relief supply–demand imbalance during emergency logistics response.

3.4.2. Inventory Control
Inefficient humanitarian inventory control model caused major negative consequences for response to HR activities and therefore, there is a need for the development and analysis of a humanitarian IM (Ozguven and Ozbay, 2013). Ozbay and Ozguven (2007) presented Hungarian inventory control model for single commodity and proposed a heuristic algorithm to find the optimal amount of initial stock so that no disruption occurs during the delivery and consumption processes. Lodree and Taskin (2009) presented a stochastic inventory control problem for determining the optimal level of supply chain readiness with respect to hurricane preparedness. Taskin and Lodree (2010) presented a stochastic programming model with recourse for multi period inventory control problem. It is aimed to determine an optimal ordering policy which the procurement/production decisions are given to minimize the expected total cost. They also applied the simultaneous backward reduction algorithm heuristic to find the optimal set of scenarios to represent the underlying distribution. McCoy and Brandeau (2011) developed an inventory model to analyze the interaction between a stockpile and a downstream refugee camp or relief operation. They considered two different decisions as (1) how to partition a fixed budget between stockpiling and shipping costs and (2) given the shipping budget determined by the budget partition, how to ship relief items from the stockpile. It is also suggested a rolling horizon solution approach to better handle demand uncertainty. Ozguven and Ozbay (2012) presented a case based stochastic inventory control model and estimate the minimum safety stock level for minimizing costs of storage, surplus, shortage and adjustment in HL activities. Salas et al. (2012) presented two mixed-integer stochastic programming models to support the decision process of inventory policies for HR. The first model aimed to minimize the total cost which included the ordering cost, the purchasing cost, shortage cost, inventory cost and disposal cost for the multi period inventory problem. The second model takes into consideration the expiry dates for perishable products. Lodree et al. (2012) proposed a TSSP model for managing disaster relief
inventories from the perspective of a single manufacturing facility. It is aimed to minimize total cost of production, pre-storm transportation, holding, shortage and the cost of redistributing. Rottkemper et al. (2011) presented a MIP model for inventory relocation planning in humanitarian operations in order to minimize unsatisfied demand and maximize operational cost. A numerical example taking into account malaria in Burundi has been developed in order to evaluate the contribution of the model and the solution method to inventory relocation planning in humanitarian operations and to demonstrate its applicability. Ozguven and Ozbay (2013) proposed p-level efficient points method for integrated RFID and stochastic humanitarian IM model with multi commodity. It is determined to the optimal emergency inventory levels to prevent possible disruptions at the minimal cost. Then the neural network is trained to reach the optimum inventory levels using the training data and target inventory levels obtained from the proposed model based on these calculations. They also proposed the simultaneous perturbation stochastic approximation (SPSA) method to find the estimation of the gradient and compared with Levenberg-Marquardt (LM) algorithms to evaluate the performance of SPSA. Jaska et al. (2013) proposed a system dynamic approach inventory control and costs in a humanitarian supply chain to compare the total costs of two warehouses for conditions of transshipment is allowed and transshipment is not allowed. Wang et al. (2014b) analyzed four options of the relief order quantity approach which are insourcing and outsourcing for reactive response and proactive response for perishable and unperishable goods. Unit price, unit cost, unit inventory cost, unidirectional transportation cost, and unit monitoring cost for outsourcing approach are taken into consideration. They also evaluated social value (delay time and supply quantity) and economic cost (production cost, inventory cost, transportation cost and monitoring cost). Yadavalli et al. (2014) considered a continuous review two substitutable perishable product disaster inventory model and an adjustable joint reordering policy for replenishment is adopted. The life of perishable inventory and demand is analyzed as exponentially distributed and Poisson process, respectively. Das and Hanaoka (2014) developed a humanitarian disaster relief inventory model that assumes a uniformly distributed function in both lead-time and demand parameters.

3.4.3. Inventory Forecasting
Forecasting techniques are suitable tools for determining sufficient pre-disaster inventory and it can minimize the response time corresponding to suffering time. Xu et al. (2010) aimed to forecast agricultural product demand of post-disaster. A hybrid forecasting method which integrates the empirical mode decomposition and autoregressive integrated moving average is proposed. Sheu (2010) proposed three mechanisms including dynamic relief demand forecasting, affected area grouping and distribution priority identification for emergency logistics operations under large-scale disasters. Sun et al. (2013) proposed a fuzzy rough set model and approach to emergency material demand prediction over two universes. Peng et al. (2013) proposed a simulation model for predicting post-seismic road network and delayed information of disrupted disaster relief supply chain. And the decision trees for choosing appropriate stocking strategies are proposed. They presented a dynamic
model for selection of inventory planning strategies and forecasting methods in emergency SCM. Peng et al. (2015) tested and applied three inventory planning strategies (town order, joint order, and headquarter managed inventory) and four forecasting methods (directly, average, safety stocks, and exponential smoothing) for post-seismic supply chain risk management. They proposed a system dynamics model for examining the behaviors of disrupted disaster relief supply chain by simulating the uncertainties of road network and delayed information.

3.5. Relief Distribution Planning

3.5.1. Routing Models

Routing models for HRL in DOM are characterized as scheduling limited vehicles or resources to achieve delivery tasks in strictly limited times and there are 22 of 220 reviewed papers about routing models. De Angelis et al. (2007) proposed an ILP model for multi-depot, multi-vehicle routing and scheduling problems. The case of World Food Programme cargo planes in Angola are solved and analyzed to evaluate the effectiveness of the proposed model for vehicle routing and scheduling problem. Shen et al. (2007) proposed a two-stage model for a specific bioterrorism emergency scenario. They presented a MIP model and TS algorithm for the preplanning and operational stages. Campbell et al. (2008) examined two objective functions for classic traveling salesman problem and vehicle routing problem (VRP) that minimizes the maximum and average arrival time. Jotshi et al. (2009) also developed Gong and Batta’s (2007) model for the dispatching and routing of emergency vehicles. Hentenryck et al. (2010) formalized the single commodity allocation problem that combines resource allocation, warehouse routing, and parallel fleet routing. They applied a novel multi-stage hybrid-optimization algorithm that utilizes the strengths of MIP, constraint programming, and large neighborhood search. Mete and Zabinsky (2010) proposed a TSSP model for selection of medical supply location and distribution in disaster management. A MIP model is proposed for loading and routing vehicles to minimize total cost of warehousing and total transportation time of assigned vehicles. Bish (2011) proposed two MIP model and heuristic algorithm for bus based evacuation problem that is considered as the split delivery multi-depot VRP with inter-depot routes. Lin et al. (2011) proposed a MO IP for multi-items, multi vehicles, multi-periods, soft time windows, and a split delivery VRP in disaster relief operations. They also proposed GA and a decomposition and assignment heuristic. Özdamar (2011) proposed a mathematical model and a route management procedure for planning helicopter logistics in disaster relief. The proposed model considers both deliveries and pickups concerned with medical care and injured person evacuation. Özdamar and Demir (2012) presented last mile delivery and pickup VRP of cluster networks to minimize the estimated total travel times and maximize the vehicle utilization. The relief network is divided by using k-means partitioning heuristic. Rong et al. (2013) proposed a RO method that the transportation time is uncertain for emergency vehicle scheduling problem. The results of RO method and PSO algorithm are compared. Zhang et al. (2013) proposed amoeboid organism algorithm to find the shortest path for route selection for emergency management. Zidi et al. (2013) applied GA to both capacitated and uncapacitated VRP with time windows
for emergency relief planning. Du and Yi (2013) proposed a GA to minimize the total cost and total travel time for MO VRP. Huang et al. (2013) proposed a continuous approximation approach for relief assessment routing problem with time-sensitivity. They aim to minimize the sum of arrival times to beneficiaries. Najafi et al. (2014) developed a dynamic model for dispatching and routing vehicles and fuzzy rule based heuristic in response to an earthquake. The proposed model aims to minimize the total time until arrival at a hospital, and the total lead time to fulfill commodity needs. Wilson et al. (2014) described and evaluated four routing strategies which are static routing, centralized adaptive routing, autonomous individual routing, and collective adaptive routing. They aim to compare the performances of autonomous routing policies ASAR and autonomous collective adaptive routings with a baseline policy static routing and an alternative central adaptive routing. Zhang et al. (2014) developed a new algorithm based on biogeography-based optimization for multi-depot version of the cumulative VRP. The results of the proposed algorithm are compared with GA, PSO and ACO algorithms. According to their results, biogeography-based optimization algorithm exhibits the best performance among the competitive algorithms on the test problems. Allahviranloo et al. (2014) proposed three parallel GAs for three different reliable, robust, and fuzzy selective VRPs and the results are compared with deterministic solution. Rivera et al. (2014) applied a variable neighborhood descent metaheuristic to the multi trip cumulative capacitated VRP that aims to minimize the sum of arrival times at affected sites. Talarico et al. (2015) proposed two mathematical models and large neighborhood search for ambulance routing problem that aim to minimize the latest service completion time among the green and red code patients. Naa and Banerjeea (2015) proposed a MILP for specifying on the tactical routing assignment of several classes of evacuation vehicle.

3.5.2. Location-routing Models
Location-routing (LR) models aim to model and solve facility location problems including the distribution routes in HRL. Balcı et al. (2008) proposed a MIP for allocation and routing problem for last mile distribution in HR operations. Han et al. (2011) proposed Lagrangian relaxation method to solve the warehouse location and the fleet routing and scheduling problem for emergency material delivery. Wohlgemuth et al. (2012) proposed a multi stage MIP and a TS heuristic in order to avoid delays and increase equipment utilization for last mile disaster planning and logistical operations in a disaster relief chain. Afshar and Haghani (2012) considered finding the optimal locations as well as vehicle routing and pick up or delivery schedules for integrated supply chain logistics in real-time large-scale disaster relief operations. It is aimed to minimize the total amount of weighted unsatisfied demand over all commodities, times, and demand points. Rath and Gutjahr (2013) proposed a MO optimization model for the warehouse location–routing problem in disaster relief. An exact solution method based on a MILP formulation with a heuristically generated constraint pool is proposed in order for solving the single-objective constrained optimization problem. It is aimed to minimize the opening cost, the operative budget, and maximize the covered demand. A real world case for an earthquake is illustrated. Wang et al. (2014a) proposed a nonlinear integer open LR
model for relief distribution problem considering travel time, the total cost, and reliability with split delivery. They implemented the non-dominated sorting GA and non-dominated sorting differential evolution algorithm to solve the proposed model. Rennemo et al. (2014) present a three-stage stochastic model for a LR problem with stochastic elements as demand, capacity of the vehicle fleet and the state of the infrastructure. Ruan et al. (2014) proposed a two stage approach for location of distribution center, allocation of medical aid points and routing of helicopters and vehicles. Ahmadi et al. (2015) developed a multi-depot LR model considering network failure, multiple uses of vehicles, and standard relief time. They proposed TSSP with random travel time to ascertain the locations of distribution centers. A VNS algorithm is also applied to deterministic model. Pérez-Rodríguez and Holguín-Veras (2015) developed an integrated inventory allocation and routing problem and inventory allocation with point-to-point distribution for single and multi-commodity problem. They aimed minimize the total travel and handling costs and deprivation costs at the time of deliveries which is proposed by Holguín-Veras et al. (2013).

3.5.3. Fleet Management
Fleet management in HR consists of controlling, coordinating and facilitating several transportation modes and related activities. Some papers are proposed for evaluating and improving fleet management in HR. For example, Pedraza Martinez et al. (2011) conducted a survey more than 40 interviews in four large international humanitarian organizations at headquarters, regional and national level for understanding how international humanitarian organizations manage their field vehicle fleet management. They used a theoretical framework to identify the critical factors affecting fleet management. Van Wassenhove and Pedraza Martinez (2012) presented a case study based on visits and interviews with international humanitarian organizations by using OR for vehicle fleet management in humanitarian operations. Pedraza-Martinez and Van Wassenhove (2012) identified suggestions of objectives and constraints for vehicle fleet management evidence-based project in close collaboration with four of the largest international humanitarian organizations. Pedraza-Martinez and Van Wassenhove (2013) proposed a DP for solving replacement problem of International Committee of the Red Cross in four countries as Afghanistan, Ethiopia, Georgia, and Sudan. They proposed 100,000 km replacement policy that performs better than the 5 years and 150,000 km one. Eftekhar et al. (2014) presented a LP to identify optimal vehicle procurement policies for International Committee of the Red Cross engaged in development programs. They also developed a stylized quadratic control model by using results of the LP. Besiou et al. (2014) used SD methodology for gaining insights into the critical characteristics of humanitarian vehicle supply chain. They analyzed three different vehicle supply chain structures that are centralized, hybrid, and decentralized vehicle supply chain systems. Vehicle supply chain structure is examined the trade-off between cost efficiency and service level of international humanitarian organizations operations in a single country. Afsar et al. (2014) proposed an exact method based on column generation and two metaheuristics
derived from iterated local search are proposed for the case with flexible fleet size in HRL.

3.5.4. Integrated Distribution Models
Some contributions integrated some approaches for HRL in DOM. 31 of our 220 papers have tackled the integrated problems together. Sheu (2007) proposed a novel emergency logistics distribution approach based on fuzzy clustering and MO DP model. It is aimed to maximize the time varying relief demand fill rate and minimize the time-varying distribution costs. Yi and Kumar (2007) proposed an ACO metaheuristic at minimizing the unsatisfied demand over all commodities and that of unserved wounded people waiting at demand nodes and emergency units. Tzeng et al. (2007) formulated a fuzzy MO programming method for relief distribution problem that aims to minimize the total cost and travel time, and maximize the demand satisfaction. Yi and Ozdamar (2007) proposed an integrated location-distribution model for coordinating logistics support and evacuation operations in disaster response activities. A mixed integer multi-commodity network flow model is proposed that treats vehicles as integer commodity flows rather than binary variables. Yan and Shih (2009) developed MO, mixed-integer, multiple-commodity network flow model for emergency roadway repair and relief distribution planning. They also adopted a weighting method for MO roadway repair and relief distribution problem. Vitoriano et al. (2009) presented a GP for minimizing cost and maximum ransack probability of links, and maximizing minimum reliability in links. Li et al. (2011) proposed a TSSP model and L-shaped method solution approach for sheltering network planning. Ben-Tal et al. (2011) applied RO for dynamic traffic assignment problems with time dependent demand uncertainty. RO is compared with deterministic solution and sampling based stochastic programming solution. Vitoriano et al. (2011) proposed a network flow model which takes into consideration load and vehicle. They also proposed a GP for satisfying cost, time, equity, priority, reliability and security attributes. Ortuño et al. (2011) proposed a static flow model to obtain a planning of the humanitarian aid distribution, considering six conflicting criteria through a lexicographic GP model. Huang et al. (2012) developed performance metrics as equity, efficiency and efficacy for relief distribution. They proposed last-mile delivery problem heuristics for comparing developed performance metrics. Rottkemper et al. (2012) presented a mathematical programming for inventory relocation for taking into account disruption to minimize fixed and variable transportation costs, replenishment, inventory holding and penalty costs for unsatisfied demand under demand uncertainty. Zhang et al. (2012) presented MIP model for the multiple-resource multiple-response emergency resource allocation problem considering secondary disasters. They also propose a heuristic algorithm with high-possibility high-priority rule based on LP and network optimization. Berkoune et al. (2012) proposed a MIP to minimize total transportation time for disaster response. Branch and bound algorithm, fast construction heuristic and GA are proposed and the results are compared with each other. Zheng and Ling (2013) propose a cooperative optimization method and TS algorithm for MO fuzzy optimization problem of emergency transportation planning in disaster relief supply chains. Najafi et al.
developed a robust approach for MO, multi-mode, multi-commodity, and multi-period stochastic model to manage the logistics of both commodities and injured people in the earthquake response. It is aimed to minimize the total (weighted) unserved injured people, the total (weighted) unsatisfied demands and the total vehicles utilized in the response. Edrissi et al. (2013) focused on three integrated problems as building renovation problem, emergency LA problem and network improvement problem. They proposed a heuristic approach for solving three different problems, simultaneously. Gonçalves et al. (2013) presented a TSSP for distribution of humanitarian aid in Ethiopia. The demand and road accessibility is taken as uncertainty. Chang et al. (2013) proposed a greedy-search-based GA for allocation and scheduling problem. They aimed to minimize the unsatisfied demand, the time to delivery and total transportation costs. The results of the proposed approach are better than the MO GA and standard greedy algorithm when time to delivery is taken into consideration. Liberatore et al. (2014) proposed a hierarchical multi-criteria optimization problem for recovery operations and distribution of emergency goods. The different criteria are taken into consideration in optimization model as maximum arrival time, total served demand, maximum ransack probability in the distribution plan, global security measure, minimum used arc reliability in the distribution plan, and global reliability measure. They also proposed a three-level lexicographic model to solve the multi-criteria model. Liu and Guo (2014) proposed a lexicographic optimization approach for minimizing fill rate and total cost of facilities, procurement, recruiting of helicopters and distribution. Demand, amount of critical population, and probability of scenario is taken into consideration as stochastic parameters in MO, stochastic MINLP. Tirado et al. (2014) developed a dynamic flow model that is builds upon Ortuño et al.’s (2011) static model to obtain an operation scheduling through a time horizon. Jin et al. (2014) proposed a MIP for selecting the location and network flow of an on-site clinic to support first-aid treatment near disaster areas. Du and Peeta (2014) proposed a bi-level stochastic optimization model to address the pre-disaster investment planning problem that seeks to enhance network survivability to reduce the post-disaster expected response time for the surviving networks under different disaster scenarios. Abounacer et al. (2014) proposed an epsilon-constraint approach for MO location and transportation problem for disaster response. Ransikarbum and Mason (2014) proposed a MO integrated network optimization model for supply distribution and network restoration phases of HL operations. They presented an experimental design and a case study for investigate the fairness-or-equity-based solutions under constrained capacity, budget and resource limitations. Balcik et al. (2014) proposed a decomposition-based heuristic approach for multi-vehicle sequential resource allocation for a nonprofit distribution system. The proposed model is applied to food redistribution from donors such as restaurants and grocery stores to agencies such as soup kitchens and homeless shelters. Sheu and Pan (2014) proposed a MILP model to design a centralized emergency supply network which consists of shelter network, medical network, and distribution network. Sheu (2014) applied a structural equation models to obtain survivor perception-attitude-resilience. The parameters of the resilience perception for MIP are obtained using the 1162 responses of conducted questionnaire. The structural equation model is used as parameters in
MIP. He aimed to propose a centralized logistics distribution by considering survivor resilience maximization and the cost of logistics distribution of relief and services minimization. Bastian et al. (2015) developed a multiple criteria decision analysis model and GP for stochastic, mixed-integer, weighted GP to optimize network design, logistics costs, staging locations, procurement amounts, and inventory levels. Rancourt et al. (2015) presented a mathematical model and real case study for food distribution in Kenya. They considered the welfare of all stakeholders involved in the response system.

3.6. Debris Cleaning and Recovery Operations
There are limited number of research in recovery planning phases especially in debris collection and re-used processes (Ergun et al., 2010; Ozdamar and Ertem, 2015). Resources (FL, truck) have to be allocated that will not be adequate sufficiently to accelerate the debris collection and disposal process, while minimizing its impact (Ergun et al., 2010). Chen et al. (2011) proposed a MIP, local search heuristic, and ACO algorithm approach for multi depot vehicle-routing problems with time windows problem. This problem is considered for repairing damaged infrastructures after a disaster. Fetter and Rakes (2012) proposed MIP for LA of temporary disposal and storage reduction facilities in support of disaster debris cleanup operations. Liberatore et al. (2013) proposed a three level lexicographic problem of planning for recovery of damaged elements in the distribution network that combines time, reliability, security, and demand satisfaction. Hu and Sheu (2013) developed a MO LP model for minimizing total reverse logistical costs, corresponding environmental and operational risks, and psychological trauma experienced by local residents for a novel reverse logistics system for post-disaster debris. Aksu and Ozdamar (2014) proposed a dynamic path based mathematical model that identifies criticality of blockages and clears them with limited resources for planning of road restoration efforts during disaster response and recovery. Özdamar et al. (2014) presented a MIP and constructive heuristic approach for both stochastic and deterministic versions of the debris cleanup operations. Çelik et al. (2015) defined a stochastic debris clearance problem for determining a sequence of roads to clear in each period such that benefit accrued by satisfying relief demand is maximized. They also proposed heuristic approaches that a heuristic based on a continuous-time approximation and heuristics for approximate tree search for testing of the proposed solution approaches. Most of the current research on DOM focuses on mitigation, preparedness, and response processes.

3.7. Decision Support Systems in HRL
DSS help individuals and/or group decision makers for making a critical decision in HRL. There are some DSS based fuzzy logic and/or MCDM approaches. Pettit and Beresford (2009), Oloruntoba (2010), Zhou et al. (2011), and Celik et al. (2014) identified critical success factor of the emergency relief. The reasonable organizational structure, effective emergency information, government unity of leadership, modern logistics technology, and continuous improvement are identified as critical success factors of the emergency management (Zhou et al. 2011). Celik et
al. (2014) applied AHP based on type-2 fuzzy sets for evaluating the critical success factors in HRL. Rodriguez et al. (2010) proposed DSS for non-governmental organization to assess different disaster scenarios by using the available information, historical data and knowledge. Turgut et al. (2011) proposed a decision support system based on analytic hierarchy and fuzzy analytic hierarchy process methods for a disaster logistics center location selection. The five main criteria and eleven sub-criteria are obtained via questionnaires that are applied to specialists working in the Istanbul center of disaster coordination. Peng (2012) proposed six different MCDM approach for evaluating earthquake vulnerability of 31 Chinese regions. Hadiguna et al. (2014) proposed DSS for evaluating the possible evacuation facilities by using MCDM approach and object oriented programming. Kou et al. (2014) presented an integrated expert system to quickly assess the disaster based on the combination of fuzzy expert system and four MCDM methods which are TOPSIS, PROMETHEE, AHP and GRA for using in parallel computation. Gralla et al. (2014) make a conjoint analysis survey to measure the trade-offs among the multiple objectives for HRL. They developed a piecewise linear utility function as an objective function among the five attributes: the amount of cargo delivered, the prioritization of aid by commodity type, the prioritization of aid by delivery location, the speed of delivery, and the operational cost. According to their results, effectiveness (delivering more cargo in a short time frame) is determined as the primary objective, and efficiency (cost) is the least important. Wex et al. (2014) developed a decision support model for minimizing the sum of completion times of incidents weighted by their severity. Monte Carlo-based heuristic, the joint application of eight construction heuristics and five improvement heuristics, and GRASP metaheuristics are proposed for computationally comparison. Yang et al. (2014) proposed data envelopment analysis for allocation of reserving relief supplies by considering the risk, cost, equity and effectiveness attributes. Vitoriano et al. (2015) proposed a DSS based fuzzy rule for NGO’s to assess consequences in the earlier stage after a disaster, and another one for last mile distribution of humanitarian aid. Nappi and Souza (2015) identified ten main criteria and 36 sub-criteria for selection and location of temporary shelters.

3.8. Other Operations

Some papers highlight a research problem that is less popular than the location, inventory distribution, or recovery problems, but still present a significant improvement in HRL. For example, Adivar and Mert (2010) proposed a fuzzy LP model for international relief planning that can apply the uncertain information while maximizing the credibility of the international agencies in the most cost efficient way. Gatignon et al. (2010) compared the decentralization and centralization supply chain of IFRC’s HR. Duque and Sörensen (2011) proposed two metaheuristics to maximize the accessibility to the regional center after a disaster. Falasca and Zobel (2012) presented bi-criteria IP model for assignment of individual volunteer and volunteer groups to task. Yi et al. (2010) applied generic simulation model to model hospital operations in a disaster situation. They aimed to develop a methodology for capacity estimates of hospitals in disaster situation. Peeta et al. (2010) defined the link upgrading problem under a limited budget and a disaster scenario, with the aim of effective post-disaster response, and applied their
heuristic approach to earthquake preparedness of Istanbul. Günneç and Salman (2011) evaluated and modelled several probabilistic measures of connectivity and dependency among link failures of transportation network in case of a disaster. They proposed several metrics based reliability and performance of network reliability/dependency and compared them applying highway system of the Istanbul case. They used a Monte Carlo sampling algorithm to estimate the measures under interest for the computationally difficult case of independent link failures for comparison. Mohan et al. (2013) presented a discrete event simulation model for improving the efficiency of a nonprofit organization. Ergun et al. (2014) analyzed the use of information technologies tool to improve last-mile supply distribution. They introduced a cooperative game theory model and explored insights about the conditions under which multi-agency coordination is feasible and desirable. Faturechi and Miller-Hooks (2014) developed a bi-level, three-stage stochastic mathematical program with equilibrium constraints for quantifying and optimizing travel time resilience in roadway networks. They also applied a progressive hedging algorithm. Lassiter et al. (2015) proposed a dynamic and flexible framework for allocating and training a limited number of volunteers to a variety of tasks to minimize the total unmet task demands, where the demand for each task group is uncertain. Chen et al. (2015) presented a behavioral supply chain model using the cellular automata which incorporates the spirit of behavioral game theory.

4. DISCUSSION

4.1. Stochastic Parameters
Applying stochastic variables and parameters is required to model decision making process in preparedness and response against disasters. Liberatore et al. (2013) and Hoyos et al. (2015) analyzed 27 papers and 101 papers on stochastic parameters in HRL. In our literature review, we also analyzed 74 papers between January 2007 and May 2015 which used stochastic parameters in mathematical model. According to the our review, TSSP is a mostly applied technique (25 papers) to HRL (Chang et al. (2007), Günneç and Salman (2007), Mete and Zabinsky (2007), Shen et al. (2007), Mete and Zabinsky (2010), Peeta et al. (2010), Rawls and Turnquist (2010), Salmeron and Apte (2010), Falasca and Zobel (2011), Li et al. (2011), Rawls and Turnquist (2011), Verma and Gaukler (2011a), Verma et al. (2013), Döyen et al. (2012), Lodree et al. (2012), Noyan (2012), Rawls and Turnquist (2012), Davis et al. (2013), Gonçalves et al. (2013), Klibi et al. (2013), Balci and Ak (2014), Kelle et al. (2014), Verma and Gaukler (2014), Rath et al. (2015), Renkli and Duran (2015)). In addition, RO is also applied to HRL (Jabbarzadeh et al. (2014), Ben-Tal et al. (2011), Lassiter et al. (2015), Najafi et al. (2013), Rong et al. (2013), Lu and Sheu (2013), Lu et al. (2013)).

demand, price, minimum demand fraction (Balcik and Ak (2014)), demand, amount of critical population (Liu and Guo (2014)), demand, amount of sent commodity (Lodree et al. (2012)), Demand, amount of sent commodity, amount of unsatisfied demand (Döyen et al. (2012), Günneç and Salman (2007)), demand, amount of sent commodity, time, unsatisfied demand (Mete and Zabinsky (2007)), demand, capacity of the vehicle fleet, the state of the infrastructure (Rennemo et al. (2014)), demand, critical population, survival rate, number of transfer population, time, relief workers required (Salmeron and Apte (2010)), demand, disaster intensity (Chakravarty (2014)), demand, lead time (Ertem et al. (2010), Das and Hanaoka (2014)), demand, quantity of in-kind relief item donations, monetary donations (Falasca and Zobel (2011)), demand, road accessibility (Gonçalves et al. (2013)), demand, supply, cost (Bozorgi-Amiri et al. (2011)), demand, the damage level of the network (Noyan (2012)), demand, the proportion of stocked material, the amount of commodity shipped, the available capacity on link (Rawls and Turnquist (2011), Rawls and Turnquist (2012), Rawls and Turnquist (2010)), demand, time, the amount of supply delivered, unfulfilled demand (Mete and Zabinsky (2010)), demand, transportation capacity (Hong et al. (2015)), demand, travel time (Hentenryck et al. (2010)), demand, unsatisfied demand (Rottkemper et al. (2012)), disaster randomness, link failure distributions (Du and Peeta (2014)), disruption effect on costs, disaster impact, demand, number of days’ worth of food to provide (Bastian et al. (2015)), Distance (Verma and Gaukler (2011a)), earthquake damage, distance (Verma and Gaukler (2014)), health levels of casualties, travel time (Wilson et al. (2013)), inventory, shortage, cost (Salas et al. (2012)), life of an inventory (Yadavalli et al. (2014)), location, number of evacuation, accessibility (Li et al. (2012)), probability of link failures, network reliability (Günneç and Salman (2011)), probability of region, probability inventory, probability of condition (Jaska et al. (2013)), relief feed rate of relief suppliers (Sheu and Pan (2015)), road accessibility, cost (Rath et al. (2015)), road accessibility, delayed information (Peng et al. (2015)), road destruction (Ahmadi et al. (2015)), scheduled task volunteer demand, cumulative unfulfilled task demands, robust error term for task needing skill (Lassiter et al. (2015)), set of possible spill zones, set of possible spill profiles (Verma et al. (2013)), survivability of the infrastructure (Renkli and Duran (2015)), survival probability of link with and without investment (Peeta et al. (2010)), number of injured people, amount of commodity demands, suppliers’ capacities, hospitals’ capacities (Najafi et al. (2013)), total evacuees, cost, amount of commodity, surplus amount for commodity, shortage amount for commodity (Li et al. (2011), Kelle et al. (2014)), travel time (Rong et al. (2013), Wilson et al. (2014), Özdamar et al. (2014), Zhang et al. (2013)), travel time, capacity limitation (Faturechi and Miller-Hooks (2014)), travel time, demand (Shen et al. (2007) Lu and Sheu (2013), Lu et al. (2013)), travel time, path complexity (Yuan and Wang (2009)), unmet demand, quantity of supplies, fraction of demand, supply changing factor, demand changing factor (Davis et al. (2013)), unreliable road link, coverage (Salman and Yücel (2014)). In recent reviews of optimization models for emergency logistics (Caunhye et al., 2012; de la Torre et al., 2012), it has been noted that there has been little research in the area employing stochastic models. According to the literature, only Rennemo et al. (2014) proposed a three-stage stochastic
programming approach. These stochastic parameters are demand, capacity of the vehicle fleet and the state of the infrastructure. Hence, more studies that are considered multi stochastic parameters can be proposed for future studies.

4.2. Objectives in Humanitarian Relief

In this section, we analyzed the objective of proposed mathematical models. Single objective models are preferred instead of MO models (106 papers versus 79 papers), since they are easier to solve.

4.2.1. Single Objective

Liu (2014)), maximizing the expectation of network resilience (Faturechi and Miller-Hooks (2014)), maximizing reliability and expected performance (Peeta et al. (2010), Günneç and Salman (2011)).

Figure 7: Paper distribution based on objective functions

4.2.2. Multi Objectives
There are total 79 papers used MOs (Figure 8) and most of them are applied as two objectives. The considered MOs are as follows: Five-Objective researches: Cost, time, equity, priority (probability), reliability (Vitoriano et al. (2011), Ortuño et al. (2011)), Four-Objective researches: cost, staging locations, procurement amounts, and inventory levels (Bastian et al. (2015)), risk, cost, equity, effectiveness (Yang et al. (2014)), time, reliability, security, demand satisfaction (Liberatore et al. (2013)), Three-Objective researches: unsatisfied demand, time, cost (Zhan et al. (2014), Chang et al. (2013), Hentenryck et al. (2010), Shui et al. (2008) ), unsatisfied demand, time, satisfaction (Lin et al. (2011)), unsatisfied demand, cost, fairness (Ransikarbum and Mason (2014)), cost, fairness, lifesaving utility (Huang et al. (2015)), cost, ransack probability, reliability (Vitoriano et al. (2009)), cost, time, satisfaction (Tzeng et al. (2007)), costs, risk penalty, psychological cost (Hu and Sheu (2013)), coverage, cost, quantity of goods transported (Rath et al. (2015)), demand shortage, responsiveness, equity (Hong et al. (2015)), distance, operational cost, psychological cost (Sheu and Pan (2014)), distance, risk, cost (Doerner et al. (2009)), fatalities, suffering, efficiency (Wilson et al. (2013)), risk, coverage, travel time (Nolz et al. 2011), sum of people evacuated, cost, psychological intervention cost (Hu et al. (2014)), time, cost, equity (fairness) (Nolz et al. (2010), Tirado et al. (2014)), time, cost, reliability (Wang et al. (2014a)), time, cost, risk (Zheng and Ling (2013)), time, unsatisfied demand, reliability (Liberatore et al. (2014)), unsatisfied cost, injured people, vehicle utilization (Najafi et al. (2013)), Two-Objective researches: minimization of cost and time (Sheu (2007), Pérez-Rodriguez and Holguín-Veras (2015), Du and Yi (2013), Bish (2011), Ahmadi et al. (2015)), unsatisfied demand, unserved wounded people (Yi and Kumar (2007), Yi and Ozdamar (2007)), minimization of cost and maximization coverage (Barzinpour and Esmaeili (2014), Zidi et al. (2013), Esmaeili and Barzinpour (2014), Klibi et al.
minimizing unsatisfied demand and time (Shen et al. (2007), Abounacer et al. (2014), Najafi et al. (2014), Li et al. (2012)), minimizing the value of bid and maximizing quantity of allocated item (Ertem et al. (2010), Ertem ve Buyurgan (2011)), unused donations, equity (Balci̇k et al. (2014)), unsatisfied demand, cost (Barzinpo̦ur et al. (2014)), cost, credibility (Adivar and Mert (2010)), cost, fairness (Rennemo et al. (2014), Liu and Guo (2014)), cost, profit (Wang et al. (2014b)), cost, resilience (Sheu (2014)), cost, risk (Lodree and Taskin (2009)), cost, service level (Besiou et al. (2014)), cost, social value (Chakravarty (2014)), cost, undesired assignment (Falasca and Zobel (2012)), cost, utility (Allahviranloo et al. (2014)), coverage, losses (Eiselt and Marianov (2012)), coverage, social cost (Yushimito et al. (2012)), network survivability, network performance (Du and Peeta (2014)), network accessibility, makespan (Ozdamar et al. (2014)), number of casualty removed, saved people (Edrissi et al. (2013)), the roadway repair cost, distribution cost (Yan and Shih (2009)), time, risk (Gunneç and Salman (2007)), time, vehicle utilization (Wohlgemuth et al. (2012)), undersupply, oversupply (Sheu and Pan (2015)), unsatisfied demand, expected casualties (Salmeron and Apte (2010))

Figure 8: Paper distribution based on single or multi objectives

4.3. Solution Approaches

modeling (Kunz et al. (2014), Jaska et al. (2013), Peng et al. (2015), Besiou et al. (2014)), Cooperative game theory (Ergun et al. (2014)) are also applied to HRL problems.

5. CONCLUSION AND FUTURE SUGGESTIONS
This paper presented a literature review of HRL and DOM. Mathematical models, solution approaches and stochastic parameters are analyzed in detail. A total of 220 papers are analyzed that are published between January 2007 and May 2015. The FL, IM, distribution, DCRO, and DSS in accordance with the relevant HRL activities in DOM are investigated.
Mathematical models are significant instrument to address HRL problems in DOM that aim to improve decision making processes appearing. They were initially developed with well-established deterministic models. However, decisions to support HRL problem in DOM are challenging because of the uncertainties in these events. In this context, multi-stage stochastic programming can be a most appropriate tool to support decisions by considering different uncertainty because of its ability to handle uncertainty. It can be easily seen that after 2008 there is an increasing trend for multi-objective mathematical models in HRL. Multi-objective mathematical models are still a gap in different studies when compared to single objective analyses. It is necessary for researchers to take cognizance of MO functions on behalf of single objective as real life problems are rarely single objective. In addition to this, equity, efficiency and efficacy objectives should be considered in multi-objective models to reflect HR objectives better. On the other hand, more solvable solution approaches for MO problems and achieving the optimal solutions need to be revised to produce more robust and appropriate approaches in evaluating MO problems. Another research area for future studies can be reverse logistics management for recovery as debris cleaning problem (Sheu, 2007; Özdamar and Ertem, 2015), road repair, and relief delivery during recovery phase. In these problems, more operational studies are need to consider especially street address level, for example, the street information is considered in Özdamar et al. (2014) to coordinate debris cleanup operations. Volunteer management is determined as one of the preparedness activities (Altay and Green, 2006) that is suitably assigning volunteers with respect to tasks or skill levels for alleviating of the affected people (Falasca and Zobel, 2012; Lassiter et al., 2015). There are more studies for volunteer management in non-governmental and governmental relief
organizations for deciding the proper allocation of resources to realize the organizations' aims.

ACKNOWLEDGEMENT

In carrying out this research, the authors have been supported by the Yildiz Technical University Scientific Research Project Fund with Grant No: 2013-06-03-KAP01. This fund is hereby gratefully acknowledged.

REFERENCES


Shui, W., Ye, H., Zhao, J., & Liu, M. (2008). A Dynamic Multiple Objective Model of Location Problem of Emergency Logistics Distribution Centers. In *Logistics@sThe Emerging Frontiers of Transportation and Development in China* (pp. 929-934). ASCE.


388


