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Models, solutions and enabling technologies in humanitarian logistics

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ABSTRACT

We present a survey that focuses on the response and recovery planning phases of the disaster lifecycle. Related mathematical models developed in this area of research are classified in terms of vehicle/network representation structures and their functionality. The relationships between these characteristics and model size are discussed. The review provides details on goals, constraints, and structures of available mathematical models as well as solution methods. In this review, information systems applications in humanitarian logistics are also surveyed, since humanitarian logistics models and their solutions need to be integrated with information technology to enable their use in practice.

1. Introduction

Since the 1950s, the number and magnitude of disasters have grown exponentially, the number of affected people has grown in proportion (about 300 million persons per annum on the average since the 1990s) and the annual damage costs have risen to about 0.17 percent of the world GDP (Guha-Sapir, Hoyois, & Below, 2014). The International Disaster Database indicates that Asia and the Americas are the most affected continents by disasters (mostly by floods, quakes and storms) with Europe standing as the third most affected continent.

Recently, researchers have conducted various surveys on disaster management. Altay and Green (2006) emphasize lifecycle phases in disaster operations management, and later on, Apte (2009) discusses details of solution methods and limitations of proposed models designed for each phase. Natarajarathinam, Capar, and Narayanan (2009) provide a review for supply chains in times of crisis in both OR/MS and supply chain management journals. Caunhye, Nie, and Pokharel (2012) review optimization models for pre-disaster facility location, stock prepositioning, relief distribution, and casualty transportation. de la Torre, Dolinskaya, and Smilowitz (2012) focus on relief routing models with an emphasis on egalitarian and utilitarian objectives in disaster response. Galindo and Batta (2013) compare and contrast the articles in Altay and Green (2006) with recent developments in humanitarian logistics to highlight whether OR/MS researchers have addressed the aforementioned literature gaps. Anaya-Arenas, Renaud, and Ruiz (2014) discuss location and transportation models and categorize them according to their objectives, constraints and solution methods. We observe that in these surveys, recovery phase models are not as emphasized as preparedness and response models.

Here, we review the logistics models developed for the response and recovery planning phases in terms of their modeling features and formulation structures. Selected articles describe various models that are typical with respect to the latter features. We discuss vehicle representation styles that impact model solvability in capacitated vehicle routing models and categorize relevant models accordingly. We regret that we cannot cite all available papers pertaining to each category due to space limitations.

We also investigate the technological advances that facilitate the execution of proposed models and solutions on various types of information systems. The latter review leads to the observation that standard software that integrates different planning phases is needed in order to achieve unobstructed international humanitarian cooperation. The goal would be to enable global access to such software by all countries sharing emergency resources. We end the survey with concluding remarks that point out the areas that bear more improvement. We note that this survey overlaps partially with the one presented in a keynote speech (Özdamar, EURO-INFORMS Conference, July 2nd, 2013, Rome).

2. Concentration areas in humanitarian logistics research

Humanitarian logistics research is dedicated to the following three planning stages in the disaster lifecycle: (pre-disaster) preparedness phase, (post-disaster) response and recovery phases. In the pre-disaster phase, preparedness plans and risk-prevention actions, such as infrastructure and building re-enforcement, reduce

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Table 1
Models for relief delivery and casualty transport.

Citation	Model type	Objective(s)	Constraints	Solution methods
Haghani and Oh (1996)	DNF	OC	CV, D, MC, MD, SLD, TW	Lagrangean relaxation
Özdamar et al. (2004)	DNF	CUD	CV, D, LS, MC, MD, MM, SLD	Lagrangean relaxation, modified shortest path
Yi and Özdamar (2007)/Özdamar and Yi (2008)/Yi and Kumar (2007)	DNF	WUD (CUD + CUC)	CV, DP, LS, MC, MD, MF, MPS, MPQ, SLD	Exact/tour construction/Ant colony algorithm
Zhan and Liu (2011)	DNF	ETT, EUD	CV, D, DU, LS, RU, SU	Two-stage stochastic program with recourse
Afshar and Haghani (2012)	DNF	WUD (CUD + CUC)	CV, D, LS, MC, MD, PL, SLD	Exact
Najafi et al. (2013)	DNF, robust optimization	(CUD + CUC) + NV	CU, CV, DP, DU, LS, MC, MD, MF, MM, SLD, SU	Exact
Özdamar (2011)	SNF	TT	CV, DP, LS, MD, MC, MF, PAY, RE, SLD	Exact
Özdamar and Demir (2012)	SNF	TD	CV, DP, LS, MC, MD, MF, SLD	Hierarchical planning, clustering
Zhang et al. (2012)	UNF	TT (primary and secondary disasters)	D, LS, MC, MD, UV	LP based heuristic
Barbarosoğlu and Arda (2004)	UNF	TC	D, DU, MC, MD, MM, RU, SU, UV	Two-stage stochastic program with recourse
Tzeng et al. (2007)	UNF	EQD, TC, TT	D, LS, MC, MD, SLD, UV, 2 stage supply chain	Exact
Gu (2011)	UNF (fuzzy)	UD	LS, TTU, TW, UV	Exact
Balçık et al. (2008)	RE, dynamic	TC, minimax CUD(EQD)	CV, D, LS, MC, MD, SD, TW	Exact
Lin et al. (2011)	RE, dynamic	EQD, TT, UD	CV, D, MC, SD, SLD, TW, WTW	Decomposition, GA
Hsueh et al. (2008)	CVR	TT, LA	CV, DP, TTU, TW, dynamic scheduling	Route construction heuristic
Barbarosoğlu et al. (2002)	CVR	OC, RT	CV, DP, MC, PAY, RE, SD, SLD	Hierarchical planning
de Angelis et al. (2007)	CVR	SD	CV, D, MD, PL, TW	Exact
Shen et al. (2009)	1st stage: stochastic CVR 2nd stage: LP	UD, AT	CV, D, DU, RTD, SD, SLD, TTU	Exact, Tabu Search
Vitoriano et al. (2009, 2011)	CVR: goal prog.	EQD, OC, RR, RS	BUD, CV, DP, MD, STE	Exact
Berkoune et al. (2012)	CVR	TT	CV, D, MC, MD, WTW	Set enumeration heuristic, GA
Nolz et al. (2011)	CVR, covering TSP	AP, MCD, TT, UN	CV, PC, SD, STE	Memetic algorithm
Sheu (2010)	–	SD	D, DU, UV	Fuzzy clustering heuristic

Objectives – AP: number of alternative paths, AT: vehicle arrival time, CUC: cumulative unmet demand over time, CUD: cumulative unserved casualties, EQD: equity of satisfied demand, ETT: *Expected Travel Time*, EUD: expected unmet demand, FT: flow time, LA: late arrivals, MCD: maximal demand covering, NV: number of vehicles in transit, OC: operation cost, RR: road reliability, RS: road security, RT: response time, SD: satisfied demand, TC: transport cost, TD: travel distance, TT: travel time, UD: unmet demand, UN: unreachability of nodes, WUD: weighted unmet demand; **constraints** – BUD: budget for vehicles, CU: casualty uncertainty, CV: capacitated vehicles, D: delivery only, DP: delivery and pickup, DU: demand uncertainty, LS: limited supplies, MC: multicommodity, MD: multi-depot, MF: medical facilities, MM: multi-mode transport, MPS: medical personnel sharing, MSQ: medical service rates, PAY: helicopter payload, PC: population covering, PL: parking limitation, RE: refueling, RTD: response time deadline, RU: road uncertainty, SD: single depot, STE: sub-tour elimination, SU: supply uncertainty, TTU: travel time uncertainty, TW: delivery time windows, UV: uncapacitated vehicles, WTW: working time windows, SLD: split deliveries (pickups); **model types** – DNF: dynamic network flow, TS: *Time-Space Network*, UNF: uncapacitated network flow, SNF: static network flow, CVR: classical vehicle routing, RE: route enumeration.

damage in disaster prone areas. Furthermore, inventory and equipment pre-positioning enable fast relief distribution to survivors from pre-stocked commodities (Balçık & Beamon, 2008; Duran, Gutierrez, & Keskinocak 2011; Ichoua, 2010; Mete & Zabinsky, 2010; Ukkusuri & Yushimito, 2008). On the other hand, pre-positioning of shelters leads to coordinated evacuation of the population to nearby shelters (Widener & Horner, 2011). Pre-disaster models are usually stochastic due to the uncertainty of the disaster impact level. Two-stage stochastic programming (Mete & Zabinsky, 2010) and stochastic scenario analysis approaches (Balçık & Beamon, 2008; Chang, Tseng, & Chen, 2007) are frequently utilized to solve these models.

Post-disaster phases involve mass evacuation to shelters (can also be executed as a pre-event activity if notice of disaster is given), relief delivery, casualty transportation, debris collection, road clearing and regional re-development. These activities enhance post-disaster survival rates and economic growth. We review response and recovery logistics models in the following sections.

2.1. *The response phase*

Response phase logistics models fall under two major categories: a) relief delivery/casualty transport models, b) mass evacuation models. Table 1 provides a list of models related to relief delivery/casualty transport with regard to their objectives, model particulars and structure, decisions considered, and solution methods. Table 2 describes mass evacuation models in a similar fashion. In the following sections, we discuss several vehicle representation styles involving capacitated vehicle transport, and then, we classify the literature according to the latter feature and other characteristics.

2.1.1. *Vehicle representation styles in models with capacitated vehicles*

Relief delivery, casualty transport and public transit mass evacuation models are involved with vehicle routing. In relief delivery, models consider the transport of supplies to demand points by capacitated vehicles. Vehicles start their itineraries at warehouses and serve several demand points on their routes. A trip does not necessarily end at the point of origin. In casualty transport, vehicles visit several locations where casualties are waiting, pick them up and transfer them to one or more medical facilities. In mass evacuation, where threatened populations have to relocate to safe zones, evacuation may take place in personally owned cars or public transit transport. The first type of evacuation involves traffic flow management rather than individual vehicle routing. The second type of evacuation involves picking up waiting evacuees at bus stops and transferring them to shelters. In this case, bus capacity and vehicle routing issues arise. Vehicle routing in humanitarian logistics context often involves split deliveries and pickups due to the magnitude of demands.

Models that consider capacitated vehicles have restrictions related to vehicle capacity, vehicle-load conformity (such as ambulances for casualties, lorries for food), road reliability, security and accessibility, supply/vehicle availability, depot/shelter/pickup location capacity, delivery time windows, re-fueling and parking limitations, split or non-split deliveries/pickups, response time deadlines, budget limits on vehicle fleet size, and vehicle working time windows. The goals stated are usually cost/travel time-, demand satisfaction-, response

Table 2
Models for mass evacuation.

Citation	Objectives	Model type	Model features	Solution method
Chiu and Zheng (2007)	TTT	CTM(LP), CE	Multi priority group evacuation, managing traffic flow, destination selection, departure schedules	Exact
Liu et al. (2006)	Bi-level: MF, TTT	CTM (LP), CE	Traffic flow and routing	Optimization and simulation
Miller-Hooks and Patterson (2004)	NCT	Time dependent quickest flow (LP), CE	TS network, time variant travel times and link capacities	Exact
Lim et al. (2012)	TNE (weighted sum of flows)	Capacitated MCNF (MIP), CE	TS network, paths, schedules and flows	Dijkstra for paths; max flow for flows (greedy)
Cova and Johnson (2003)	TTD	MCNF(MIP), CE	Lane-based routing, intersection delay management	Successive shortest path
Naghawi and Wolshon (2012)	TNE	Multi modal MCNF, CE	Evacuation routes, flows	Simulation
Cui et al. (2014)	TCF	Nonconvex nonlinear MCNF, CE	Time variant travel times, contraflows (rescue flows), lane reversal	Exact
Kongsomsaksakul et al. (2005)	TET, TTT	MINLP: bi-level location–allocation model, CE	Pre-flood evacuation routes and shelter selection	GA
Hobeika and Kim (1998)	TET, NC	Traffic simulation model, CE	Routes and schedules	Simulation
Campos et al. (2012)	MF	MCNF (LP): maximum flow, CE	Non-intersecting paths to shelters, link capacities	Iterative heuristic
Chen and Chou (2009)	NCT, DT, TTT, ATS	Simulation, PT	Bus assignment to routes, single trip, contraflows	Simulation
Perkins, Dabipi, and Han (2001)	TTT	Simulation, PT	Pre-set routes, bus departure times, single trip	Simulation
Mastrogiannidou et al. (2009)	TTD	Simulation, PT	Bus assignment to pickup stops based on shortest time, multiple trips	Cluster first, route second
Bish (2011)	TET + MET	CVR, RE, PT	Split delivery, multi depot, multiple trip	Constructive heuristic
Murray-Tuite and Mahmassani (2003)	TTT, WT	CVR, PT	Vehicle routes from their point of start in the network (anywhere) to pickup to shelter	Exact
Liu and Yu (2014)	TNE, TTD	CVR, PT	Bus stop capacity, evacuee to stop allocation, single trip	Exact
Song et al. (2009)	TTD	Stochastic CVR, PT	Demand uncertainty, evac. deadline, shelter selection	Simulation based GA
He et al. (2009)	TET	Stochastic LR (MIP), PT	Shelter selection, bus fleet size, routes, demand uncertainty	GA, hill climbing, ANN
Sayyady (2007), Sayyady and Eksioglu (2010)	TC, TET, WT	DNF-TS (MIP), PT	Pedestrian routes, bus routes, single trip	Tabu Search
Margulis et al. (2006)	TNE	RE, PT	Bus assignment to preset routes, multiple trips	Exact
Na et al. (2012)	MET, TC (secondary evacuation)	RE, PT	Route assignment (with secondary evacuation), capacitated buses and hospitals	Exact

Objectives – TTT: Total Travel Time, TTD: Total Travel Distance, TET: Total Evacuation Time, DT: Delay Time, NCT: Network Clearance Time, MET: Maximum Evacuation Time, WT: Waiting Time of evacuees, TCF: Costs of Flows, TC: Travel Cost, ATS: Average Traffic Speed, TNE: Total Number of Evacuees, NC: Number of Casualties, MF: Maximum Flow; **model types** – LP: Linear Program, MIP: Mixed Integer Program, BP: Binary Program, MINLP: Mixed Integer Nonlinear Program, CTM: Cell Transmission Model, MCNF: Minimum Cost Network Flow, CE: Car evacuation, PT: Public Transport, LR: Location-Routing, CVR, RE, DNF-TS as defined in Table 1.

time-, and road-risk related. Among these, egalitarian goals (satisfying all beneficiaries equally), and utilitarian goals (minimizing sums rather than mini-max objectives) should be differentiated (Bish, 2011; Campbell, Vandenbussche, & Hermann, 2008; de la Torre et al., 2012; Huang, Smilowitz, & Balçık et al., 2012).

Below we discuss the styles in which capacitated vehicles are represented in models. They affect the size of the models solved, and therefore, have an impact on solution times.

A. *DNF approach*. In the Dynamic Network Flow (DNF) approach vehicles are represented as integer valued flows that are linked with commodity flows in a multi-period (dynamic) network flow (NF) model. Vehicle flow variables have link (*from–to* nodes) indices and a *time* index that indicate the time of vehicle traversal over a link.

i. *DNF with time–space* (DNF-TS) *networks*. In DNF-TS models where a time–space (TS) network is used by creating a copy of the network for each time interval in the planning horizon. This structure leads to (T^2N^2) vehicle related integer variables where T is the length of planning horizon and N is the number of nodes in the network (Haghani & Oh, 1996).

ii. *DNF excluding time–space networks*. In DNF models where travel times are embedded in equations as time lags (Özdamar, Ekinci, & Küçükyazici, 2004), the number of vehicle related integer variables reduce to (TN^2). In all types of DNF models, once the mixed integer DNF is solved, a post-processing stage has to be activated. At this stage, vehicle routes are constructed from vehicle and commodity flow information. Yi and Özdamar (2007) accomplish the latter by solving a Linear Program (LP).

B. *SNF approach*. The Static Network Flow (SNF) is a single period NF model applied on a rolling horizon basis. All other features of the SNF are similar to those of the DNF model. The SNF model has (N^2) integer variables; therefore, it is more efficient. Özdamar and Pedamallu (2011) compare both DNF and SNF models to show that the sizes of SNF instances that can be solved optimally are twice as those of the DNF instances.

C. *RE approach*. The Route Enumeration (RE) approach has a preprocessing stage where all feasible routes between all pairs of supply and demand nodes are constructed. This set of R routes is then fed to a Mixed Integer Program (MIP) as an input vector. Vehicles are then optimally assigned to these routes to satisfy demand. Here, vehicles are represented by binary variables with vehicle, route and time indices. The dynamic RE model has (vRT) binary variables, where v is the number of vehicles (Balçık, Beamon, & Smilowitz, 2008). A setback in this approach is the cardinality of R that can be as large as ($2^{N-2}M\,(N-M)$) where M is the number of depots in a network with N nodes. In large scale relief networks, the construction of R routes becomes computationally intractable and the solution of the MIP requires substantial computation time. In public transit mass evacuation models, the Transportation Department may assign R pre-defined itineraries for all buses. In that case, the cardinality of R is at their discretion.

D. *CVR approach*. In the Classical Vehicle Routing (CVR) approach each vehicle is represented by a binary variable that specifies the link, vehicle, and tour indices. This results in (vrN^2) binary variables, where r is the number of trips allowed for each vehicle. Routes are explicitly constructed by the CVR model and there is no need for pre- or post-processing stages. Yi and Özdamar (2007) compare the CVR model with the SNF model in terms of model size and exact solution time. The researchers observe that the CVR approach inflates the model size considerably. As a matter of fact, in emergency logistics, the cardinality of vr can be quite large.

2.1.2. Classification of relief delivery and casualty transport literature

A. The dynamic/static network flow (DNF/DNF-TS/SNF) models.

DNF/DNF-TS models. Models for relief delivery: Cost related goals. Haghani and Oh (1996) consider a DNF-TS model with routing, transfer and inventory carryover links. Vehicle and commodity flows are coupled by vehicle arrival time windows and the goal is to minimize operation costs. The solution involves a Lagrangean Relaxation approach that solves very small networks (10 nodes). *Demand satisfaction goals.* Özdamar et al. (2004) introduce a multi-modal DNF transport model with limited supplies and dynamic vehicle availability where the goal is to minimize the cumulative unmet demand over T. Two solution approaches, a Lagrangean Relaxation and a modified shortest path heuristic, are proposed. Afshar and Haghani (2012) model a seven-layer relief delivery supply chain network (the FEMA standard) using a DNF-TS model where features such as storage space, parking space, and inbound/outbound vehicle flow limitations are introduced. The goal is to minimize cumulative unmet demand over T.

Integrated models for relief delivery and casualty transport: *demand satisfaction goals*. Yi and Özdamar (2007) introduce a DNF Location-Routing (LR) model with the goal of minimizing the cumulative prioritized unmet requests. The model selects and locates temporary medical facilities, enables sharing medical staff among facilities, and imposes finite medical service rates. The researchers solve scenarios with relief networks of up to 60 nodes within 2 minutes of computation time. Yi and Özdamar (2007) solve this model using a two-stage Ant Colony Optimization heuristic where the ants build routes in the first stage and commodity flows are optimized in the next by solving the maximum flow problem. Instances with relief networks of up to 80 nodes and 55 vehicles are solved near-optimally. Özdamar and Yi (2008) propose a constructive node-insertion heuristic and solve the same instances faster, but with slightly worse solution quality.

SNF models. Integrated models for relief delivery and casualty transport: *travel time/distance related goals.* Özdamar (2011) proposes a model for coordinating helicopter logistics in medical supply delivery and casualty pickup. The goal is to minimize total flight time plus stopping times. Fuel feasibility and itinerary length limits are taken care of in the post processing stage. The case study involves a relief network with more than 70 helipads scattered over Istanbul (Turkey). Özdamar and Demir (2012) solve large-scale relief delivery and casualty pickup scenarios within a hierarchical planning framework. Recursive clustering is applied to demand nodes in the relief network and the method ensures consistency of supply and hospital service availability at different network aggregation levels. The researchers solve scenarios of up to 1000 nodes near-optimally and verify the efficiency of the approach on a Katrina (New Orleans) flooding scenario (Özdamar, Demir, Bakır, & Yılmaz, 2013).

B. The Route Enumeration (RE) models. Relief delivery models: cost related goals. Balçık et al. (2008) propose a dynamic relief delivery model with limited supplies and vehicle availability constraints. The goal is to minimize transport, backorder, and lost sales costs where critical items such as tents and blankets are backordered. Regularly consumed items such as food and water become lost sales when demand is not met. In the first stage, the researchers identify all possible sets of demand points that can be served in one trip. Each such set represents nodes on a feasible route. The order of nodes on each route is then optimized by solving the TSP. Then, the set of feasible routes are fed into the model and vehicle assignments are made. *Demand and travel time related goals.* Lin, Batta, Rogerson, Blatt, and Flanigan (2011) define three goals in their model: minimize cumulative unmet demand, minimize travel time, and minimize the pairwise difference between demand fill rates at nodes. These are then merged into a single fitness function in a Genetic Algorithm (GA) that enumerates routes. A second solution approach clusters demand nodes first and enumerates all routes within each cluster. The GA is found to be slow but its delivery rate is higher than the clustering approach. The clustering approach solves a scenario with three million houses grouped into nine clusters within 2 minutes.

C. The Classical Vehicle Routing (CVR) models. Relief delivery models: Demand related goals. de Angelis, Mecoli, Nikoi, and Storchi (2007) schedule cargo planes that carry out food delivery in Angola. In their model, the number of planes and supplies are limited, overnight parking near warehouses is mandatory with limited parking space, split deliveries are not allowed, and take-offs are allowed only in daylight due to security reasons. The goal is to maximize satisfied demand. The solution to the problem is obtained in 2 hours by CPLEX. *Cost, road security and demand equity goals.* Vitoriano, Ortuno, and Tirado (2009), and Vitoriano, Ortuno, Tirado, and Montero (2011) propose a multi-objective model for relief delivery. The goals are minimizing transport and operating costs, minimizing the maximum looting probability (based on the number of vehicles traversing arcs), and minimizing the maximum percentage of unmet demand over nodes. The model contains of a transport budget and sub-tour elimination constraints. The Haiti Quake case study is analyzed with three depots, 12 transfer nodes, and nine demand zones to construct the routes of 300 trucks. Berkoune, Renaud, Rekik, and Ruiz (2012) impose a vehicle itinerary length limitation in a model where the goal is to minimize travel distance. A GA is proposed and tested on networks with up to 60 demand nodes and three suppliers. The gap from the best solution is found to be 20 percent.

Integrated relief delivery and casualty transport models: Cost and response time related goals. Barbarosoğlu, Özdamar, and Cevik (2002) propose an integrated CVR model for helicopter pickup and delivery operations and solve very small instances with a two stage hierarchical planning approach. *Travel time related goals.* Hsueh, Chen, and Chou (2008) use a delivery/pickup CVR model that considers the reverse logistics of relief delivery as well. Travel times are assumed to be time-variant. A node insertion heuristic constructs the initial routes and then improved by node exchange with the goal of minimizing total travel time. A 100 node relief network with ten vehicles is tested.

D. Models involving uncertainty. Relief delivery models: Demand and response time related goals. Shen, Dessouky, and Ordóñez (2009) propose a two-stage CVR type model for antidote distribution in large scale bioterrorist attacks, assuming that demand and travel times are uncertain. Their goals are to minimize unmet demand and satisfy service deadline to avoid deaths. The pre-planning stage is modeled by chance constrained programming designed for split delivery vehicle routing and solved by Tabu Search. In the operational stage, the solution of the previous model is fixed for vehicles and a LP determines loads. Tests are conducted on a network of 50 demand nodes. *Road risk related goals.* Zhan and Liu (2011) consider path availability risk using the NF model and minimize both expected travel time and unmet demand. An infrastructure risk in terms of road network uncertainty is discussed in Nolz, Semet, and Doerner (2011). The problem is to locate and deliver water dispensers so as to cover as much of the population as possible. Road risks are minimized by the following goals: minimize the maximum hazard over all arcs of each path, maximize the number of alternative paths, minimize the unreachability of all alternative paths, and maximize the number of paths whose risk value is below a threshold. The researchers model the problem as a TSP with a single capacitated vehicle and solve it using a multi-objective Memetic Algorithm.

Integrated relief delivery and casualty transport models: Demand and congestion related goals. Najafi, Eshghi, and Dullaert (2013) add the goal of minimizing the number of traveling vehicles to the cumulative unmet demand objective in a multi-objective DNF risk model where demand uncertainty exists. Robust Optimization method is used to solve each objective hierarchically. A small case study involving 16 nodes, five hospitals, and four vehicle types is solved.

E. Network flow models without capacitated vehicles (UNF). In Table 1, we also cite UNF relief delivery models that consider cost related (Barbarosoğlu & Arda, 2004), demand satisfaction related (Gu, 2011), and time, cost and equity based (Tzeng, Cheng, & Huang, 2007 ; Zhang, Li, & Liu, 2012) objectives. Demand, supply and road uncertainties are considered by Barbarosoğlu and Arda (2004) who propose a two-stage stochastic program with recourse to minimize costs. Tzeng et al. (2007) propose a deterministic two stage supply chain with split deliveries and limited supply availability. Gu (2011) considers travel time uncertainty and delivery time windows.

2.1.3. Mass evacuation models

Mass evacuation models concentrate on Car Evacuation (CE) and traffic flow management, and also, on evacuation by public transit (PT). CE models are frequently represented by link capacitated Minimum Cost Network Flow (MCNF) models with vehicle flow per hour limitations over links. Traffic simulation tools are also used to observe the impacts of lane reversals, intersection delay management, and traffic direction reversals on traffic flows. Some models consider contraflows of rescuers.

PT models optimize bus routes consisting of a depot, several pickup stations and a shelter. These models consist of *pickup only* vehicle routing problem. In some models bus departure times are also considered to relieve traffic congestion. Shelter selection may also become a part of the problem leading to a Location-Routing (LR) model. In no-notice evacuation, a bus conducts a single trip, however, in short notice evacuation, it can carry out multiple trips. The objectives in PT models can be time related, evacuee number related, cost and flow related. Vehicle representation is in accordance with CVR and RE classification. In the following sections, we review relevant CE and PT models according to model functionality and structure.

A. Traffic flow management models: Car Evacuation (CE). *Cell Transmission Models* (*CTM*). CTM (Daganzo, 1994) partition the car traffic network into grids and control the traffic flow advancement over adjacent grids (cells). These models are obtained by transforming differential equations of traffic flow into simpler difference equations resulting in an LP. A bi-level CTM is given by Liu, Lai, and Chang (2006) which maximizes traffic flow and minimizes travel time. A combined optimization-simulation model is used to route the traffic flow. Chiu and Zheng (2007) consider multi-group evacuation where some groups (e.g., nurses) have priority over others. Ben-Tal, Chung, Mandala, and Yao (2011) tackle dynamic traffic assignment problem such that traffic risks are minimized. The researchers use Robust Optimization to deal with traffic flow uncertainty.

Location–allocation models. Kongsomsaksakul, Yang, and Chen (2005) provide a bi-level location–allocation model for demand allocation to shelters and route selection. Both network links and shelters have capacity limits. The researchers use a Genetic Algorithm (GA) to minimize evacuation time and total travel time.

MCNF models. Miller-Hooks and Patterson (2004) minimize network clearance time in a time dependent quickest flow model (an LP) where travel times and link capacities are time-variant. Cova and Johnson (2003) discuss an MIP model for lane based evacuation routing where delays due to intersections and lane changes are considered. Solution method is based on successive shortest path algorithm. A mixed integer capacitated maximum flow model is proposed by Lim, Zangeneh, Baharnemati, and Assavapokee (2012) where the goal is to maximize number of evacuees. Dijkstra's algorithm is used to find paths and a greedy maximum flow algorithm is used to determine the flows. A multimodal NF model is described in Naghawi and Wolshon (2012) where routes are optimized by simulation. Campos, Bandeira, and Bandeira (2012) solve a maximum flow problem with an iterative heuristic to identify two independent paths form each affected area to shelters. The idea is to minimize intersection delays and traffic congestion. Cui, An, and Zhao (2014) minimize the costs of evacuation and the contraflows of rescuers as well as lane reversal costs. They solve the nonlinear MCNF model using BARON (GAMS).

B. Public Transit models (PT). *Simulation models.* Chen and Chou (2009) deal with the assignment of buses to pickup points in a no-notice evacuation. Simulation with contraflows is used to solve the problem so that traffic speed, system travel time, and network clearance time are minimized.

CVR/LR/RE models. Murray-Tuite and Mahmassani (2003) minimize travel time including evacuee waiting time in a CVR model where capacitated vehicles (that can be anywhere in the network) pickup evacuees and transfer them to shelters. Margulis, Charosky, Fernandez, and Centeno (2006) propose a RE model that decides on the number of trips made between given pairs of pickup points and shelter nodes. Bus capacity cannot be exceeded on its trip and the goal is to maximize total number of evacuees. He, Zhang, Song, Wen, and Wu (2009) develop a stochastic LR model with demand uncertainty. Shelter selection, bus fleet size, and bus routes are optimized using a combined metaheuristic (GA, hill climbing and Artificial Neural Networks). Song, He, and Zhang (2009) propose a LR model that selects pickup points among many in the city and optimize bus routes simultaneously in a no-notice evacuation. Evacuation time has a deadline and the number of evacuees is uncertain. The goal is to minimize total travel time and the researchers propose simulation based GA. Bish (2011) proposes both CVR and RE type models with multiple bus depots, split delivery and capacitated shelters in a short-notice evacuation. A route construction and improvement heuristic is implemented. Na, Xueyan, and Mingliang (2012) propose a RE model that minimizes maximum evacuation time and the costs of secondary evacuation that involves re-directing patients to other hospitals. The model assigns routes for capacitated buses, shelter capacities are also limited. Liu and Yu (2014, chap. 4) define a CVR model where two sets of decisions are made simultaneously: evacuees are optimally allocated to capacitated pickup points (based on walking distances from parking lots) and optimal bus routes are constructed. The goals are to minimize total travel distance and maximize the number of evacuees transported.

DNF-TS models. Sayyady (2007) and Sayyady and Eksioglu (2010) represent waiting time of evacuees over a TS network in a no-notice evacuation. The model is solved by a Tabu Search that identifies vehicle routes with the goal of minimizing total evacuation time, travel time, and waiting time.

2.2. The recovery phase

In the recovery phase, planning issues are concerned with proper damage assessment, an effective reverse logistics system for debris disposal and recycling, and infrastructure rebuilding with minimum cost and duration. Table 3 summarizes model features for the recovery phase. Recovery models usually concentrate in two areas: road and other infrastructure restoration, and debris management that includes removal, disposal, and recycling. According to a FEMA report (2007), debris cleanup operations consist of two phases. During the first phase, the goal is to clear debris from evacuation routes and other important paths to ensure traffic flow in affected areas.

Table 3
Models for recovery phase.

Citation	Objective(s)	Model type/features	Solution method
Fetter and Rakes (2012)	Debris facility setup and debris logistics cost	Debris facility setup, location selection, transport (MIP)	Exact
Hu and Sheu (2013)	Costs of transport, delay risk, psychological	Multi-stage debris collection supply chain (LP)	Exact, Pareto by constraint adding
Chang and Nojima (2001)	Measuring travel time extension due to blocked links in network	Network accessibility measure based on shortest path extensions	–
Sohn (2006)	Link criticality measure for network vulnerability	Population based Chang and Nojima (2001) network accessibility index	Measuring link criticality by sequential link dropping on GIS map
Allen, Liu, and Singer (1993)	Measuring areal network accessibility	Measure based on average length of all paths between all pairs of nodes in area	–
Jenelius and Mattsson (2012)	Measuring unmet travel demand	Grid based accessibility measure	GIS software
Chen and Tzeng (1999, 2000)	1) Minimize travel time, work time, idle time of work teams 2) Maximize traffic flow	Bi-level LRM (CVR): repair due date, dozer travel times, limited no. of dozers	Multi objective GA
Feng and Wang (2003)	Maximize repaired road length, number of repaired links, minimize risk of work teams	LRM (CVR, multi-tour TSP): manpower, dozer clearance capacities	Lingo-VRP package
Özdamar et al (2014)	Maximize network accessibility over repair time	Recursive LRM (parallel machine scheduling model): dozer work sequence with clearance times and travel times	Accessibility based link group criticality and makespan related heuristics
Tuzun Aksu and Özdamar (2014)	Maximize cumulative number of open paths over repair time	Dynamic PRM (MIP): repair sequence under resource constraints	Exact
Yan and Shih (2009)	Minimize maximum repair and delivery costs, demand satisfaction equity	LRDM (DNF-TS, MIP)	Exact, 3 step heuristic
Maya Duque and Sörensen (2011)	Minimize weighted shortest paths between pairs of regions	LRDM (binary MCNF): repair budget	GRASP metaheuristic
Chen et al. (2011)	Weighted relief delivery and unmet demand	LRDM (CVR): non-split deliveries	GA
Liberatore et al. (2012)	Minimize relief delivery time, unmet demand, maximize arc reliability	LRDM (binary MCNF): repair budget	Exact, lexicographic optimization
Matisziw and Murray (2009)	Identify most critical p links (maximize flow)	Path based network vulnerability model (BP): path aggregation constraints	Exact

Model types – LRM: Link based Repair Model, PRM: Path based Repair Model, LRDM: Link based Repair/Delivery Model, CVR, MCNF, DNF-TS, MIP, LP, BP defined as in Tables 1 and 2.

This operation should start immediately after the disaster strikes and complete within 72 hours because road blockages impede rescuers, emergency services, and lifeline support (Kobayashi, 1995). In the second phase, all other debris are collected, reduced, transported, temporarily stored, recycled, and disposed. These operations could take months. Examples of the first and second phases of post disaster debris management are given by Lauritzen (1998). In the next two sections, we summarize models for infrastructure restoration and subsequent debris management.

2.2.1. Models for infrastructure restoration

Network accessibility measures. Road restoration activities involve clearing roadside debris and restoring the road network in order to open up evacuation routes and other important paths. A similar analogy can be made for the restoration of other types of infrastructure such as power and fiberoptic networks that share similar topologies. Hence, any infrastructure repair operation can be conducted efficiently by identifying the optimal order in which critical blocked links in the network are cleared. The goal would be to restore major paths as early as possible while maximizing network accessibility throughout the operation. Thus, network accessibility measures need to be defined. Chang and Nojima (2001) define it as the length extension in post-disaster shortest paths between all pairs of locations in a road network. Sohn (2006) enhances this measure by weighing locations according to their populations and traffic densities. A road or link criticality index calculates the impact of its blockage on network accessibility. Sohn (2006) and Jenelius and Mattsson (2012) adopt a slow sequential approach that closes one link at a time to observe its impact on the whole network. This approach does not take the combined impacts of groups of blocked links into account; hence, the restoration plans based on sequential criticality index ordering might be suboptimal.

Link and path based repair models. Link based repair models represent roads as arcs in the network and path based models represent them as nodes. A path is an ordered set of nodes. Path based models are more compact than link based models and may converge faster because they explicitly consider links shared by multiple paths. These models involve path related goals leading to maximizing network accessibility or minimizing network vulnerability. On the other hand, link based models involve goals such as maximizing length of restored links, maximizing network flow or minimizing the repair operation's completion time (makespan).

A. Link based repair models (LRM). *CVR type.* Chen and Tzeng (2000) propose a bi-level link based model where a due date is imposed for the completion of tasks, travel times between tasks are explicitly considered, and repair resources are unlimited. First level goals are to minimize travel, work, and idle times of work teams. Second level goal is to maximize traffic flow. Chen and Tzeng (1999) use a multi-objective GA to solve this problem on a network with 24 nodes. Feng and Wang (2003) consider limitations on dozers, manpower, and debris clearing capacity. The goals considered are maximizing total length of accessible links, maximizing total number of restored links, and minimizing risk of work teams. The formulation involves a multi-tour TSP (each link is visited only once). The model is tested on a 50 node network with ten damaged links.

Parallel machine scheduling type. Özdamar, Tuzun Aksu, and Ergunes (2014) aim to maximize the cumulative network accessibility measure defined by Chang and Nojima (2001) over the road repair duration. The researchers propose heuristics that favor both repair operation makespan and network accessibility. Dozer clearance capacities, dozer travel times between tasks, and number of available dozers make up the model restrictions.

B. Link based integrated repair and relief delivery models (LRDM). *DNF-TS type.* Yan and Shih (2009) propose a link based DNF-TS model with work team trips and relief material flows over repaired roads. An equity constraint exists for demand satisfaction. The goal is to minimize maximum repair and relief delivery costs. A three-step heuristic is proposed where blocked links are prioritized first, worker schedules and commodity flows are optimized next. A 46 node network with 25 repair points is solved in 900 CPU seconds.

CVR type. Chen, Peña-Mora, and Ouyang (2011) propose a non-split delivery CVR model to distribute relief over repaired roads. GA is used to optimize a weighted objective composed of maximizing relief delivery and minimizing unmet demand.

MCNF type. A network flow model is proposed by Liberatore, Ortuño, Tirado, Vitoriano, and Scaparra (2012) for relief distribution over a network with broken linkages. A budget constraint is imposed on fixing links implicitly limiting the equipment and the number of work teams used in the operation. Several goals, such as delivery time, satisfied demand, and reliability of arcs are proposed. Maya Duque and Sörensen (2011) address a similar repair problem under budget constraints using a fixed cost network flow formulation for minimizing the cost of flows from each rural center to the nearest regional center.

C. Path based repair models (PRM). Network vulnerability models. A path based approach is adopted by Matisziw and Murray (2009) who identify a fixed number of critical node and arc blockages that would prevent traffic flow the most. The model addresses both mitigation and response phase planning (to protect most critical linkages in preparedness phase and recover them first in response phase) and aims at maximizing flows over broken source-sink paths. The most important feature of this model is the introduction of path aggregation constraints that dispose of the necessity to enumerate all source-sink paths. The researchers illustrate the mechanics of the model on a network of 23 nodes and 34 arcs.

Network accessibility models. Tüzün Aksu and Özdamar (2014) propose a dynamic path based model that identifies the optimal repair order of blocked links during a three-day work shift given a limited number of equipment. The goal is to open all access paths from each location in the network as early as possible and this maximizes the cumulative network accessibility throughout the restoration operation. Two real road network problems with up to 400 links (of which 70 are broken) are solved within 1 hour of computation time.

2.2.2. Models for debris management

Brown, Milke, and Seville (2011) provide a wide review on post disaster waste treatment options. Different types of waste result from different disaster categories. While construction and demolition waste (C&D) results from all disaster types, sediments result from hurricanes, quakes and floods; green waste results from all but fires; and ash results from quakes and fires. The major contribution to debris comes from C&D. In the survey, the researchers emphasize the environmental, social, economic, and legal aspects that are the concern of the second phase in debris management. In particular, the speed needed in disposal due to health hazards, the requirement of accuracy in calculating disposal costs, psychological effects of allowing property owners to deconstruct, and re-use C&D waste (Denhart, 2009), vermin related public hazards (Petersen, 2004) are mentioned. The second phase debris management models usually concentrate on locating temporary storage and recycling facilities around the affected area as well as determine debris transportation routes.

Supply chain models. Fetter and Rakes (2012) present a facility location model for locating temporary disposal and storage reduction facilities to support debris clean-up operations. The objective is to minimize the costs of debris collection, recycling, and disposal as well as the fixed costs of enabling recycling technology at temporary facilities. Hu and Sheu (2013) propose a reverse logistics chain for debris disposal with four stages: on site processing and recycling, nearby temporary site processing and recycling, mass processing by permanent facilities, disposal and recycling, and reproduction for construction products (bricks). A network model that enables material balance at each stage is developed and the goals are to minimize logistics costs, minimize risk based penalty due to delay of debris removal, and minimize psychological costs of delay. The researchers analyze the Wenchuan quake (2008 China) as a case study. They observe that risk induced costs are decreased by 37 percent at the expense of 243 percent of an increase in logistics costs.

3. Use of information systems in humanitarian logistics

It is very difficult, if not impossible, to implement solution procedures in real life without a proper information system that bundles mathematical models in a user-friendly interface. Moreover, information systems have the potential to act as a liaison between practitioners and academic researchers in humanitarian logistics as well as among different disaster lifecycle stages. For a literature review for the use of information systems in humanitarian logistics and future research directions, Sangiamkul and van Hillegersberg (2011) and Ortuño et al. (2013) can be referred. Blecken and Hellingrath (2008) compare five practitioner software (i.e., SUMA, LSS, HELIOS (HELIOS, 2013), LogistiX, Sahana) and conclude that critical decisions such as inventory management, supply planning, routing and scheduling are not addressed by any of them. In addition to the five software discussed in Blecken and Hellingrath (2008), Ortuño et al. (2013) review Disaster Management Information System (DMIS), FleetWave®, and Humanitarian Free and Open Source Software (HFOSS) (Tucker, Morelli, & de Lanerolle, 2011) as well. Ortuño et al. (2013) also report the humanitarian relief efforts where the software was used. Howden (2009) explains where information systems can play a role from a disaster operations management lifecycle perspective. Chib and Komathi (2009) extend the framework for technology-community-management model to assess vulnerability in Asian countries for disaster recovery. Here, the use of different types of information systems in humanitarian logistics is addressed for the response and recovery phases. In Table 4, we provide academic studies and applications that correspond to different technologies.

3.1. Maps and geographic information systems

Similar to the scarcity of relief supplies and equipment; field data for the location and impact of the disaster, the availability of the transportation infrastructure, and estimated demand quantity are scarce resources in the aftermath of disasters. Maps and Geographic Information Systems (GIS) are vital to provide these field data. GIS research on disaster management, GIS applications, and potential future study topics are listed in Cutter (2003). Disaster risk maps and alerts for upcoming disasters are developed to assist relief operations. A good example is the Global Disaster Alert and Coordination System (GDACS) of United Nations and European Commission (GDACS, 2014). GDACS analyses GIS data, maps, Satellite Mapping Coordination System, field data (e.g., reports, photos/videos, Geo-Pictures), mass and social media information and presents the estimate of the disaster impact, risk, and magnitude via a global map. GDACS is now accessible by a smart phone app called iGDACS.

Several researchers have integrated their models with maps and GIS. Chang et al. (2007) use a scenario planning approach for rescue center location problem in conjunction with GIS software for flood emergencies. Saadatseresht, Mansourian, and Taleai (2009) propose an evolutionary approach using GIS software for solving a spatial multi-objective evacuation problem. Mete and Zabinsky (2010) address prepositioning of medical supplies using a simulation and visualization environment called RimSim (Campbell, Mete, Furness, Weghorst, & Zabinsky, 2008). Widener and Horner (2011) develop a model for deciding the size and location of aid distribution facilities for post-hurricane settings. Their model utilizes GIS and spatial optimization technologies to solve p-median and capacitated median type problems.

An application of GIS based techniques for needs assessment is provided in Benini, Conley, Dittemore, and Waksman (2009). The

Table 4
Summary of the use of information systems in humanitarian logistics.

Citation	Maps and/or GIS	Coordination network	Smart phone apps	Other technologies
GDACS (2014)	GIS data, map	Mass and social media	iGDACS	Satellite, geo-pictures
Chang et al. (2007)	GIS	N/A	N/A	N/A
Saadatseresht et al. (2009)	GIS	N/A	N/A	Spatial multi-objective optimization
Mete and Zabinsky (2010)	N/A	N/A	N/A	RimSim (a simulation and visualization environment)
Widener and Horner (2011)	GIS	N/A	N/A	Spatial optimization
Benini et al. (2009)	GIS algorithms	UN joint logistics cluster	N/A	NASA satellite imagery
ACAPS (2014)	Heat maps	Community of practice	NOMAD	N/A
MapAction (2014)	GIS, GMES satellite imagery, QGIS	UN assessment and coordination team	N/A	GoogleEarth, portable satellite data modem, hand held GPS units
SandyCoworking (2013)	GoogleMaps	List of available spaces	N/A	Ushahidi platform
Humanitarian OpenStreetMap (2014)	GIS	Web portal	Available	Aerial imagery
Chen et al. (2011)	ArcGIS	Collaborative GIS	Mobile resource requesting ability	Resource tracking and management
Zografos and Androutsopoulos (2008)	GIS	N/A	N/A	Database, human machine interface
Jotshi et al. (2009)	ArcGIS	N/A	N/A	Data fusion, Tele-Atlas, and HAZUS
Demir and Özdamar (2013)	ArcGIS	N/A	Android app	On-line user interface
Huang et al. (2013)	OpenStreetMap	Urban search and rescue	SMS	Matlab, ArcGIS, Python
Pasupathy and Madina-Borja (2008)	N/A	American Red Cross	N/A	Excel, Access, VBA, SQL
Vitoriano et al. (2009)	Logistics maps	Web based tool	N/A	Java, Access, GAMS
Tomaszewski et al. (2006)	Open source GIS	Geo-collaborative web portal	PDA or tablet	MapBuilder API and JetSpeed Portal
Özgüven and Özbay (2013)	N/A	N/A	N/A	RFID
Yang et al. (2011)	N/A	N/A	N/A	RFID

Assessment Capacities Project (ACAPS) is one example dedicated to better deal with the needs assessment operations in the response phase (ACAPS, 2014). Software such as MapAction depicts the needs and specific locations around the disaster area (MapAction, 2014). Crowd sourcing is a tool that was used during the Hurricane Sandy (SandyCoworking, 2013). This specialized crowd map helped businesses and individuals to move to safer places by populating information about available spots around the area. Humanitarian OpenStreetMap initiative provides key geographic data to help humanitarian responders. It is built by volunteers recording GPS, aerial imagery, and geographic data after a catastrophic event (Humanitarian OpenStreetMap, 2014).

3.2. Integrated systems

Information systems are used in a variety of application areas such as damage and needs assessment, locating aid distribution facilities, and vehicle routing in the response and recovery phases. Unfortunately, not many studies can be reported that integrate available technologies with proper mathematical models through several disaster lifecycle stages.

A comprehensive study for the response phase is given in Chen et al. (2011) which addresses the challenge of construction equipment allocation, management, and routing for urban search and rescue operations under scarce resource disaster relief environment. The researchers combine three technologies (i.e., GIS, resource tracking and management, and decision making by a mathematical model) in a framework with mobile resource requesting ability. Zografos and Androutsopoulos (2008) develop an integrated decision support system (DSS) for hazardous material transportation and emergency response decisions. The implemented DSS has logistics, crisis management, database, GIS, and human machine interface subsystems.

Jotshi, Gong, and Batta (2009) use data fusion to dispatch and route emergency vehicles with the aim of minimizing the response time; hence, maximizing the life expectancy. Data fusion technique is used in conjunction with ArcGIS, Tele-Atlas, and HAZUS technologies. Demir and Özdamar (2013) describe a hierarchical relief delivery and casualty pickup coordination system using dynamic data transferred from ArcGIS database. The system provides on-line user interface supporting access to the database from Android based hand devices. Huang et al. (2013) integrated visualization of real time crowdsourcing data on OpenStreetMap with SMS messages for demand estimation. Huang et al. (2013) implemented a routing heuristic for urban search and rescue teams.

An example of integrated software packages applied for performance management in the American Red Cross (ARC) is explained by Pasupathy and Madina-Borja (2008). Equipped with a Data Envelopment Analysis model, this tool was implemented to measure the performances of about 1000 ARC chapters with respect to criteria such as financial resources, capacity creation, service delivery, and customer effectiveness. Vitoriano et al. (2009) introduce a multi-objective model with integration of Java, GAMS, and Microsoft Access to support transport operations in disaster relief.

DMIS (World Disaster Report, 2013, p. 123) is an integrated platform that provides real time data about disasters and tools for operations of International Federation of Red Cross and Red Crescent (IFRC). This web based tool is only available for IFRC staff. Although not developed specifically for humanitarian logistics, FleetWave® (FleetWave, 2014) is a web-based enterprise fleet management software used by large humanitarian organizations such as IFRC and World Food Programme (WFP) (Ortuño et al., 2013).

3.3. Coordination networks

Coordination is one of the biggest challenges in humanitarian logistics (Balçık, Beamon, Krejci, Muramatsu, & Ramirez, 2010). Several stakeholders compete for scarce resources in a chaotic environment. Information systems provide a unique opportunity to overcome coordination challenges. There are specific tools for coordination some of which were discussed in Section 3.1. Bartell, Lappenbusch, Kemp, and Haselkorn (2006) give a review about the use of information systems in effective coordination and communication Tomaszewski, MacEachren, Pezanowski, Liu, and Turton (2006) present an example with a geo-collaborative web portal to address the coordination and collaboration challenges in a disaster relief environment. The researchers use open source software such as MapBuilder API and JetSpeed Portal.

Open source software community took responsibility to help humanitarian logisticians in the field. Humanitarian Free and Open Source Software (HFOSS) project has been working on both engaging undergrad students in FOSS community as well as *doing good with good computer science* practices. Portable Open Source

Information Tool (POSIT) and Collabit are two successful tools developed by HFOSS project contributors (Ortuño et al., 2013; Tucker et al., 2011).

In addition to specific tools, there exist non-governmental organizations that aim at increasing the efficiency of disaster response and recovery by using Information and Communication Technology at a greater scale (Aidmatrix, 2014; NetHope, 2013). The Aidmatrix Network® for Humanitarian Relief provides comprehensive supply chain management software including modules such as planning, procurement, transportation, warehouse, online ordering, distribution, fleet management, asset management, and distribution. The International Network of Crisis Mappers (Crisis Mappers Net, 2014) is a network of various stakeholders working at the crossing of disasters, novel technologies, crowd-sourcing, and crisis mapping. This network has more than 7000 members in over 160 countries, who are affiliated with over 3000 different institutions from academic researchers to actual practitioners on the field. Logistics Cluster approach is also a successful example in coordinating scarce logistical resources in a disaster area. The information flow among humanitarian organizations is managed and up-to-date maps about the available warehouses, trucks, etc. around the disaster area are released through a logistics cluster (Tomasini & Van Wassenhove, 2005).

3.4. Other technologies

Remote sensing techniques such as satellite or camera image processing are used for damage (Pesaresi, Gerhardinger, & Haag, 2007) and needs assessment (Tatham, 2009). An example for using an unmanned aerial vehicle system for needs assessment is illustrated in Tatham (2009). Radio Frequency Identification (RFID) sensors are also investigated for their use in humanitarian logistics settings. Yang, Yang, and Yang (2011) design a sensor network with a hybrid implementation of active and passive RFID tags for humanitarian logistics center management. Özgüven and Özbay (2013) discuss both off-line and on-line use of RFID information to manage inventory for humanitarian relief efforts.

From the discussions above, we observe that disaster management software cover a wide portfolio of dispersed applications; however, holistic software that integrate all phases of the disaster lifecycle are yet to be developed. Moreover, some software those seem to offer an integrated solution are not freely available to humanitarian aid workers all around the world.

4. Conclusion

According to the claims of climate scientists and the trend in disaster frequency during the recent decades, during the 21st century, residents of the earth will suffer severely from the environmental outcomes of the 20th century's technological advances (IPCC Report, 2014). Even the most optimistic views on the progress of global warming have demoralizing aspects in terms of clean water availability, temperature rise, sea level changes, droughts, floods, wild fires, and earthquakes. Global awareness of the forthcoming calamities has risen due to extensive media coverage of climate change and of the high impact disasters that took place in the last decade. Academicians have duly responded by developing mathematical models and solution algorithms that deal with different aspects of disasters. Information technologies such as GIS and remote sensing entered the field of disaster management along with mobile hand devices that enable access to/from people on the street.

The detailed discussions held here on the modeling aspects of the literature implicate that though preparedness plans can be zone based and rough, response and recovery plans have to include street address level of detail in order to construct routes for relief delivery, repair equipment delivery, detailed itineraries for rescuers, etc. Unfortunately, algorithms for commercial routing problems do not satisfy the needs of humanitarian logistics; therefore, methods that deal with large scale disasters are not readily available. Though the proposed logistics planning models have good practical features, most of the models' computational burdens might prevent them from being used in actual disasters. From practical and academic perspectives, on-line algorithms that aim at both service quality and optimal resource utilization would be most welcome in high impact disasters.

Another area of improvement would be developing more solvable models that treat all aspects of recovery in an integrated manner including debris transportation, road repair, relief delivery, and evacuation during the first phase of recovery. Although integrated models exist, the models are either oversimplified or too complex and unsolvable. Proposed metaheuristics are not yet tested on realistic size networks.

As discussed in Section 3, the developed enabling technologies that should make solution methods available to aid practitioners are quite dispersed in their functionality and accessibility. Although there have been several attempts in recent years to integrate some type of information systems into the humanitarian logistics models, the use of technology is still not prevalent in humanitarian logistics. Practitioner software lack sophisticated mathematical models, hence optimal results, but have nice graphical user interfaces and fast solutions. On the other hand, few academic researchers attempt to integrate their mathematical models into a decision support system equipped with GIS, maps, real-time data, and a user-friendly interface. Although it is not very easy to combine the best values of practitioners and academic researchers, the use of technology is a must in order to achieve success in humanitarian logistics operations. A holistic approach such as web-based Enterprise Resource Planning (ERP) systems is yet to be seen in this area. The commercial versions of such systems are readily available but they need to be adapted to disaster context. Unfortunately, most of the disaster response costs are born by governments and private damage costs by insurance companies. Unless disasters use up country GDPs more and more, government funding will probably not be made available to build a disaster-ERP, i.e., Disaster Resource Planning (DRP) software. The first step is to calculate governmental disaster costs correctly and conduct a gap analysis to validate building the DRP. In order to optimize response phase resource utilization, the DRP software and database should be globally accessible. International cooperation should be promoted to design a global disaster supply chain managed by the DRP, setting political differences aside. The challenges that lie ahead of a successful implementation is lack of real-time data, fragmented nature of humanitarian organizations, lack of commonly accepted interoperability standards among different humanitarian organizations, and not realizing the importance to balance good bookkeeping practices and to act fast in emergency relief operations. These barriers are rather concerned with the human way of doing things than with the lack of available technologies. We believe that they can be overcome with adequate determination.

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