Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 97 (2014) 2248 – 2258
Procedia Engineering
www.elsevier.com/locate/procedia

12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT, GCMM 2014

Analyzing transportation and distribution in emergency humanitarian logistics

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Abstract

Most of the disasters occur unexpectedly with respect to time, place and intensity. Due to these reasons, humanitarian logistics has attracted considerable research attention in the recent past.This paper reviews modeling parameters for objective functions and constraints in humanitarian logistics distribution. The objective functions that are realized in various humanitarian emergency operations aim to increase the supply of relief aid. In this paper, a classification based review methodology is employed to identify various cost functions and constraints for primary emergency operations in logistics viz. casualty transportation and relief distribution problems. Based on the classification, areas of future research are discussed that would be useful for key decision makers in planning logistics activities in emergency situations.The paper also serves to delineate the recent trends, challenges and research gaps in the area of Humanitarian Logistics.

Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014

Keywords: Humanitarian logistics; Casulty transportation and evacuation; Relief distribution; Objective functions; Network design; Location/allocation;

1. Introduction

The World Health Organization (WHO) defines a ‘disaster’ as any occurrence that causes damage, destruction, ecological disruption, loss of human life, human suffering, deterioration of health and health services on a scale sufficient to warrant an extraordinary response from outside the affected community or area. Earthquakes, hurricanes, tornadoes, volcanic eruptions, fire, floods, blizzard, drought, terrorism, chemical spills, nuclear accidents

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Selection and peer-review under responsibility of the Organizing Committee of GCMM 2014
doi:10.1016/j.proeng.2014.12.469

are included among the causes of disasters, and all have significant devastating effects in terms of human injuries and property damages.

Most of the disasters strike without prediction and expectation leading to limited preparation for mitigating the same. Disasters create a massive demand for relief aids that include food, medicines, shelter, water and other resources. Efficient emergency operations are required to increase the supply of relief aids. Managing emergency humanitarian logistics operations is more complex due to the risks and uncertainties that accompany any disaster. This poses difficulties in the planning and mitigation phases in the event that a disaster is expected. In the response phase, damages in transportation medium such as road, rail, compounded with uncertainties in demand, supply and environmental conditionsfurther complicateshumanitarian operations.

Modeling, optimization and simulation are the major tools to address and overcome these challenges. Other tools like fuzzy logic (Sheu et al.,(2005)), queuing theory (Mendoncaand Morabito (2001)), decision theory, and referencepoint method are also used. Most researchers employmodeling and optimization to derive solutions to problems in emergency humanitarian logistics.Emergency operations in logistics include facility location, casualty transportation, relief distribution, stockpre-positioning and evacuation among many others (Caunhye et al., (2011)). Generally governments, military, civil society, and humanitarian organizations are responsible for undertaking such emergency relief operations. Disasters also test the capacity of different emergency operations in working together to deliver the best possible relief aid.

A major part of research in extent literaturefocuses on transportation models alone. Horner and Widener (2011) , Hamedi et al., (2012), Campos et al., (2012), Ozdamar (2011), Song et al., (2009) and Barbarosoglu and Arda (2004) have formulated emergency transportation models, which achieve the multiple objectives of minimizing the travel time and travel cost.

In humanitarian operations quick response anddemand satisfaction take precedence over profit as being important parameters while delivering relief. In other words, the right goods should reach the right place, at the right time (within the shortestpossible time) to those who need it the most.

This article attempts to distill various objective functions and constraints from the literature on humanitarian logistics, with the aim of identifying research gaps and giving direction to future research work.

2. Humanitarian logistics

Humanitarian logistics is defined as “the process of planning, implementing and controlling the efficient, cost effective flow and storage of goods and materials as well as related information from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people”.

Humanitarian agencies prioritize to maximizing the demand met, maximizing the response and prevention of further damage. To support these priorities, response or lead time reduction is an important consideration. Any reduction in the lead time can have a significant positive impact for the beneficiaries. Humanitarian logistics differs from the logistics operations in commercial supply chains because of uncertainties in route selection, changing facility capacity, changing demand, safety issues, unused routes and other challenges like disrupted communication systems, limited availability of resources, and the need for efficient and timely delivery (Balcik et al., (2008)).

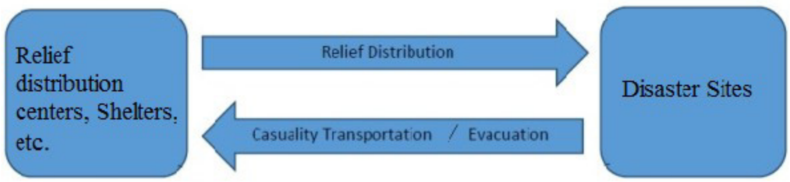

Fig.1. Primary Emergency humanitarian logistics operations

Humanitarian operations should be planned accordingly to get maximum response and minimum loss. Costa et al.,(2012) identified the following actions that need to be developed for better performance in humanitarian operations: transport, storage and handling, distribution and performance evaluation. In this paper we focus on the two primary operations-casualty transportation/evacuation and relief distribution. The major challenging areas under these primary operations are vehicle routing, network design, and location /allocation. Vehicle routing, location and allocation of various logistics problems has been the focus of many recent researches (Anbuudayasankar et al., (2012), Sivakumar et al., (2012), Anbuudayasankar et al., (2010),). But most of these researches are applicable only in ordinary logistics problems. Some of researchers developed distinct models for emergency logistics operations due to its high degree of uncertainty (Abounacer et al., (2014), Liberatore et al., (2014), Safeer et al., (2014), (Wilson et al., (2013), Davis et al., (2013)).

2.1.1Network design and vehicle routing

Critical problem in vehicle routing is to find out the shortest time path between origin and destination. Unlike classical vehicle routing problems, the emergency vehicle routing problem minimizes sum of arrival times instead of minimizing the cost. Network design includes defining the routes and allocating the available resources (resources being mostly vehicles and tasks being varied ones such as structure stabilization and roadway repair).The performance of a network is evaluated by network vulnerability analysis and network reliability analysis. Vulnerability analysisensures the connectivity between all origin-destination pairs following a disaster. Network reliability analysis evaluates the stability of atransportation network under different circumstances.Some researchers like Hamedi et al., (2012) and Feng and Wang (2003) have studied network reliability in such emergency transportation.

2.1.2 Location / Allocation

Location allocation problem includes selecting the facilities and allocating the available resources and tasks.Facility location problems are of two types,selecting a facility from existing facilities and selecting the location for building the new facility. Location / Allocation problems are highly uncertain in terms of travel time, cost and demand.Many of these models have as an objective the minimization of cost (Davis et al., (2013), Bozorgi-Amiri et al., (2011), Charles and Lauras, (2011), Sheu,(2007)) or time (Edrissi et al., (2013),Noyan, (2012), Ji and Zhu, (2012), Zhang et al., (2012)) .Others take nodal demand (Liberatore et al., (2014), Holguín-Veras et al., (2013)) as the major objective. The main objective of allocation problem is to maximize the level of demand satisfaction that can be achieved by the effective utilization of available vehicles and resources.

2.1.3 Integrated operations

Integrated operation involves a network design, route selection, facility location and resource allocation incorporated into a single model in such a way that so as to achieve minimum time.Theapplication of these models facilitatescoordinationof all operations in during emergency relief.Time and demand are the major objectives identifiedin table3 and 6.

3. Classification of modeling parameters

3.1 Casualty Transportation and evacuation

Casualty transportation is one of the most critical actions in emergency logistics. Casualty transportation includes evacuation and people flow from affected areas to medical centers.Most of the researchers focus on minimizing the travel cost and travel time, as outlined in the Table I, II, and III.Minimization of travel time leads to improvement in overall response and is sought for identifying the right path with minimum risk for transportation.

The objective functions that are used to optimize casualty transportation operations with the corresponding constraints are depicted in Table 1, 2 and 3. Important and recurrent objective functions discussed in literature and outlined in the table 1, 2 and 3.are:

- Travel cost - Maintenance Cost, Idle time cost of vehicle and Travel distance cost.
- Loading and Unloading Time – Loading and unloading time of resources to and from the vehicle.
- Distance – Short path selection.
- Travel time – Minimum travel time.
- Evacuation time–Minimum evacuation time.
- Distance – Selection of path based on shortest path.
- Quantity– Unmet Demand and demand satisfaction, Total life saving, Number of emergency units needed

Table 1
Modeling Parameters: Network design and vehicle routing

Basis	Objective function	Author	Constraints		
			Capacity	**bounds**	**Others**
Cost	Travel cost	Hamedi et al., (2012)	-	Flow, Time, arrival and destination	-
		Taniguchi et al., (2012)	-	Time between deliveries, unmet demand	-
		Ben-Tal et al, (2011)	Vehicle, link	-	Total flow
		Viswanath and Peeta, 2003	-	Total covered area, cost	Flow
	Resource selection cost	Barbarosoğlu et al., (2002)	Vehicle	Pilot, duration	-
Time	Travel time	Yuan and Wang, (2009)	-	-	Feasible path, no circles in the path
		Feng and Wen, (2003a)	Link	Travel cost, trip time	Traffic flow, traffic control ratio
		Barbarosoğlu et al., (2002)	-	Time, distance, transshipment	-
	Loading, unloading time	Barbarosoğlu et al., (2002)	-	Time, distance, transshipment	-
	Evacuation time	Campos et al., (2012)	-	number of shelters and paths	-
Distance	Distance	Shen et al., (2008)		Demand, travel time	-
		Feng and Wen, (2003b)	-	Node, Time ,Damaged node	--
Quantity	Unmet demand	Yi and Özdamar, (2007)	Vehicle	Demand, number of vehicle	Balanced material flow, vehicle type,
	Number of emergency units needed	Yi and Özdamar, (2007)	Vehicle	Demand, number of vehicle	Balanced material flow, vehicle type,
	Total demand covered	Viswanath and Peeta, 2003	-	Total covered area, cost	Flow
	Total life saving, risk	Feng and Wen, (2003b)	-	Node, Time ,Damaged node	-
	Number of wounded people waiting	Yi and Özdamar, (2007)	Vehicle	Demand, number of vehicle	Balanced material flow, vehicle type,
		Feng and Wen, (2005)	-	Total amount of trips	Traffic inflows
	Traffic Volume	Feng and Wen, (2003a)	Link	Travel cost, trip time	Traffic flow, traffic control ratio
	Capacity	Campos et al.,(2012)	-	number of shelters and paths	-

Table 2
Modeling Parameters: Location / Allocation

Basis	Objective function	Author	Constraints		
			Capacity	**Bounds**	**Others**
Time	Transportation time	Edrissi et al., (2013)	-	Supply, Demand, Budget (cost)	-
		Yazici and Ozbay, (2007)	Vehicle, link, facility	Number of vehicle,	Flow
	Resource allocation time	Fiedrich et al., (2000)	-	Resource restriction due to local conditions	Available resources

Table 3
Modeling Parameters: Integrated

Basis	Objective function	Author	Constraints		
			Capacity	**bounds**	**Others**
Time	Transportation time	Wilson et al., (2013)	Facility	Task completion time	Location
		Ozdamar, (2011)	-	Unmet demand, commodities, total supply	Material flow
		Horner and Widener, (2011)	-	Relief demand, service level	-
		Song et al., (2009)	Vehicle	Vehicle serving time	Route continuity constraints,
	Evacuation time	Song et al., (2009)	Vehicle	Vehicle serving time	Route continuity constraints,
Distance	Distance	Song et al., (2009)	Vehicle	Vehicle serving time	Route continuity constraints,
Quantity	Total life saving	Wilson et al., (2013)	Facility	Task completion time	Location

3.2 Distribution

Distribution is the flow of resources from warehouses or medical centers to affected areas. Relief distribution provides relief in the form of food, medicines, shelters and other related relief resources to wounded people. Due to uncertainties in the post-disaster environment, maximum relief distribution can be achieved by efficient planning. Some uncertainties in post disaster environments are demand variations, link and facility damage and shortages in resources. Better relief distribution is essential for achieving demand satisfaction, reduced unmet demand (unsatisfied demand level), minimum fatality and maximum lifesaving. Most of the distribution models are single objective and deterministic(Caunhye et al., (2011)).

In relief distribution, a significant portion of the literature tries to reduce the unmet demand for improving the distribution of relief. Afshar and Haighani (2012) have proposed a mathematical model that controls the flow of several relief commodities in a supply chain from the source till the point they are delivered to the hands of recipients. Some researchers have worked on resource allocation, the resources being vehicles, commodities, or equipment (Holguín-Veras et al., (2013), Zhang et al., (2012) and Fiedrich et al., (2000)). Resource allocation involves assigning the resources without consideration for the flow. As demand increases resource allocation becomes more difficult. Initially Brown and Vassilou (1993) proposed a resource allocation model for disasters;later Fiedrich et al., (2000) introduced a better disaster allocation model.

Relief distribution operations are time and cost dependent. Davis et al., (2013) proposed a model based on relief distribution cost. The model is helpful for positioning of quantities and distribution of supplies to the affected counties based on the desired response time.

The objective functions that are used to optimize distribution operationsis categorizedin Table 4, 5 and 6.

- Relief Distribution cost
- Relief Distribution time
- Responds
- Resource allocation
- Fatalities
- Demand satisfaction
- Unmet Demand
- Total life saving
- Number of wounded people waiting

Table 4
Modeling Parameters: Network design and vehicle routing

Basis	Objective function	Author	Constraints		
			Capacity	**bounds**	**Others**
Cost	Travel cost	Ben-Tal et al, (2011)	Vehicle, link	-	Total flow
		Barbarosoglu and Arda, (2004)	Vehicle, link,	Supply	Flow
		Hamedi et al., (2012)	-	Flow, Time, arrival and destination	-
		Viswanath and Peeta, 2003	-	Total covered area, cost	Flow
	Distribution cost	Holguín-Veras et al., (2013)	-	Time between deliveries, unmet demand	-
		Vitoriano et al., (2011)	Vehicle	Total operation cost, transported load	Flow balance
	Distance	Liberatore et al., (2014)	-	Supply, delivery, demand	Unreliable arc flow, time
Time	Transportation Time	Chen et al., (2011)	Vehicle, Link	Demand, supply	Maintain the balance of in-flow and out-flow at each node
		Yuan and Wang, (2009)	-	-	Feasible path, no circles in the path
	Resource allocation time	Holguín-Veras et al., (2013)	-	Time between deliveries, unmet demand	-
	Distribution time,	Yan and Shih, (2009)	-	Relief commodities,	Repair point, flow
Quantity	Demand satisfaction	Liberatore et al., (2014)	-	Supply, delivery, demand	Unreliable arc flow, reach time,
	Unmet demand	Holguín-Veras et al., (2013)	-	Time between deliveries, unmet demand	-
		Viswanath and Peeta, (2003)	-	Total covered area, cost	Flow
		Yi and Özdamar, (2007)	Vehicle	Demand, number of vehicle	Balanced material flow, vehicle type,
	Number of emergency units and wounded people waiting	Yi and Özdamar, (2007)	Vehicle	Demand, number of vehicle	Balanced material flow, vehicle type,

Table 5
Modeling Parameters: Location / Allocation

Basis	Objective function	Author	Constraints		
			Capacity	**bounds**	**Others**
Cost	Relief Distribution cost	Davis et al., (2013)	Facility	Supply quantity, time and demand	Flow balance
		Bozorgi-Amiri et al., (2011)	Facility	Demand, amount of commodity, inventory	-
		Charles and Lauras, (2011)	Facility	DemandSatisfaction	Balance of inventory.
		Sheu,(2007)	Vehicle, facility	Relief amount	
	Travel cost	Brown and Vassiliou, (1993)	-	Resource allocation	Resource flow

Time	Transportation Time	Edrissi et al., (2013)	-	Supply, Demand, Budget (cost)	-
		Noyan, (2012)	-	Demand , damage level	-
		Ji and Zhu, (2012)	-	Amount of relief distributed, total relief	-
		Duran et al.,(2011)	-	Inventory, number of fatalities	-
		Sheu et al.,(2005)	-	Demand , relief distribution canters	Insufficient condition
	Relief distribution rate	Ji and Zhu, (2012)	-	Amount of relief distributed, total relief	-
		Sheu,(2007)	Vehicle, facility	Relief amount	-
	Resource allocation time	Zhang et al., (2012)	-	Equilibrium of supply and demand, Amount of resource	-
		Fiedrich et al., (2000)	-	Resource restriction due to local conditions	Available resources
Quantity	Demand satisfaction	Balcik and Beamon, (2008)	-	Inventory level, amount of demand, amount of supplies	-
		Brotcorne et al., (2003)	-	Demand covered	Number of vehicle
	Resources	Brown and Vassillou, (1993)	-	Resource allocation	Resource flow
	Fatalities	Paul and Hariharan, (2012)	Facility	Demand, cost associated with each sites	Inventory (stock pile expenditure)

Table 6
Modeling Parameters: Integrated

Basis	Objective function	Author	Constraints		
			Capacity	**bounds**	**Others**
Cost	Travel cost	Horner and Widener, (2011)	-	Relief demand, service level	-
	Relief distribution cost	Horner and Widener, (2011)	-	Relief demand, service level	-
		Rath and Gutjahr, (2011)	Vehicle, facility	Budget limit, delivery amount, time	Each customer can be visited at most once.
Time	Transportation Time	Abounacer et al., (2014)	Vehicle, link	supply quantity, total working time, delivery,	-
		Safeer et al., (2014)	Vehicle, facility	Supply Quantity, Demand, Capacity	Vehicle start and end locations
		Ozdamar, (2011)	-	Unmet demand, commodities, total supply	Material flow
		Mete and Zabinsky, (2010)	Vehicle, facility	Unsatisfied demand, medical supply	Prevents the loading of vehicle, Flow
		Van Hentenryck et al., (2010)	Vehicle	costs	Vehicles start and end locations
	Loading ,unloading Time	Safeer et al., (2014)	Vehicle, facility	Supply Quantity, Demand, Capacity	Vehicle start and end locations
		Ozdamar, (2011)	-	Unmet demand, commodities, total supply	Material flow

Quantity	Unmet demand	Abounacer et al., (2014)	Vehicle, link	supply quantity, total working time, delivery	-
		Afshar and Haghani, (2012)	Vehicle, facility	Commodity fow, resource flow, minimum percentage of total demand	-
		Van Hentenryck et al., (2010)	Vehicle	Total costs	Vehicles start and end locations
		Rath and Gutjahr, (2011)	Vehicle, facility	Budget limit, delivery amount, time	Each customer can be visited at most once.
		Lin et al.,(2009)	Vehicle	Satisfaction rate, delivery amount	-
	Number of emergency units.	Abounacer et al., (2014)	Vehicle, link	supply quantity, total working time, delivery	-

4. Future research direction

The major objective of disaster management is to reduce loss. Loss refers to infrastructure loss and human loss which includes the number of persons injured.. After a disaster strikes, the losses in affected areas increaseproportionately with time. This calls forquick response inproviding relief and shelter in order to minimize the loss.

Another research direction is developing a novel basisfor relief distributionin the disaster affected area- giving more priority in relief delivery to persons more affected or injured in a disaster. Other factors are that people need to be allocated to hospitals based on the type and severity of injuries. Whichminimisingthe individual or overall risk. For an efficient relief distribution planning it is required to develop a new model to achieve maximum response by taking into account the above consideration. The severity of the risk can be integrated into the model based on a ranking system that prioritizes medical aid based on severity of the injury.

Facility location model development is an important research area. In post disaster situations, the affected nodes needs to be allocated to the best facility so that relief is delivered to a particular demand point with minimum time, minimum probability of path failure,maximum path capacity between allocated facility and demand points, maximum availability of resources,balanced facility capacity and expected demand at the demand points.

There is scope for development of a pre-facility location model that is capable ofaccommodating more uncertainty and dynamic situationsThe uncertainties mentioned include variations in demand, supply, availability of resources (relief items, vehicle, trained workers etc.), whereasdynamic situations include environmental changes during the operations, barriers from the Government, political barriers and barriers from other organizations.

Other research areas which require emphasis are development of an inventory and relief distribution model that incorporates new demand patterns; capacity planning for pre-post disaster situations; and development of a more realistic humanitarian model that incorporates several moretasks and uncertainties.

5. Conclusion

Transportation models serve as critical decision making tools for providing quicker response to a disaster situation. With the help of a classification-based methodology of the literature, this paper identifies major transportation model objective functions and constraints that are mostly used in two primary relief operations- casualty transportation and evacuation and distribution. The paper gives an aerial view of the research on transportation models and will prove useful for managers and academicians for decision support and planning, and stimulating further research work in the area.Categorized list of major transportation operations that are identified from literatures are given in table 7.

Table 7
Challenging transportation operation

Network reliability analysis and path selection	Wilson et al., (2013), Taniguchi et al., (2012),Hamedi et al., (2012), Ben-Tal et al., (2011), Fang and Wakabayashi, (2011), Vitoriano et al., (2011), Song et al., (2009), Yuan and Wang, (2009), Shen et al., (2008).
Allocate people, facility and vehicle according to demand and severity	Holguín-Veras et al., (2013),Zhang et al., (2012), Bozorgi-Amiri et al., (2011),Döyen et al., (2011) Mete and Zabinsky (2010),Shen et al., (2008).
Capacity planning	Campos et al., (2012).
Inventory level	Davis et al., (2013), Bozorgi-Amiri et al., (2011) Döyen et al., (2011), Döyen et al., (2011),Charles and Lauras (2011), Mete and Zabinsky (2010).

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