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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.

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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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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 conditions further complicates humanitarian 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 (Mendonca and Morabito (2001)), decision theory, and reference point method are also used. Most researchers employ modeling 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 literature focuses 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 and demand 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 shortest possible 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 consumtion 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 (Balci 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)).

2.1.1 Network 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 analysis ensures the connectivity between all origin-destination pairs following a disaster. Network reliability analysis evaluates the stability of a transportation 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. The application of these models facilitates coordination of all operations in during emergency relief. Time and demand are the major objectives identified in table 3 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                                        |
| Cost                | Travel cost        | Hamedi et al., (2012)           | -                                                |
|                     |                    | Taniguchi et al., (2012)        | -                                                |
|                     |                    | Ben-Tal et al, (2011)           | Vehicle, link                                    |
|                     |                    | Viswanath and Peeta, 2003       | -                                                |
| Resource selection cost |                 | Barbarosoglu et al., (2002)   | Vehicle Pilot, duration                          |
| Time                | Travel time        | Yuan and Wang, (2009)           | -                                                |
|                     |                    | Feng and Wen, (2003a)           | Link                                             |
|                     |                    | Barbarosoglu et al., (2002)    | -                                                |
|                     |                    | Loading, unloading time         | -                                                |
|                     |                    | Campos et al., (2012)           | -                                                |
| Distance            | Distance           | Shen et al., (2008)             | Demand, travel time                              |
|                     |                    | Feng and Wen, (2003b)           | Node, Time, Damaged node                         |
|                      | Unmet demand       | Yi and Özdamar, (2007)          | Vehicle Demand, number of vehicle                |
|                      | Number of          | Yi and Özdamar, (2007)          | Vehicle Demand, number of vehicle                |
|                      | emergency units    |                                 | Balanced material flow, vehicle type,            |
|                      | needed             |                                 |                                                   |
|                      | Total demand       | Viswanath and Peeta, 2003       | -                                                |
|                      | covered            |                                 | Total covered area, cost                         |
|                      | Total life saving, | Feng and Wen, (2003b)           | -                                                |
|                      | risk               |                                 | Node, Time, Damaged node                         |
|                      | Number of          | Yi and Özdamar, (2007)          | Vehicle Demand, number of vehicle                |
|                      | wounded people     |                                 | Balanced material flow, vehicle type,            |
|                      | waiting            |                                 | Traffic inflows                                  |
|                      | Traffic Volume     | Feng and Wen, (2003a)           | Link                                             |
|                      | Capacity           | Campos et al, (2012)            | -                                                |

Table 2
Modeling Parameters: Location / Allocation

| Basis              | Objective function | Author                          | Constraints                                      |
|--------------------|--------------------|---------------------------------|--------------------------------------------------|
|                    |                    |                                 | Capacity                                        |
| Time               | Transportation     | Edrissi et al., (2013)          | -                                                |
|                    | time              | Yazici and Ozbay, (2007)        | Vehicle, link, facility                          |
|                    | Resource allocation time | Fiedrich et al., (2000) | -                                                |
|                    |                    |                                 | Supply, Demand, Budget (cost)                    |
|                    |                    |                                 | Number of vehicle, Facility                      |
|                     |                    |                                 | Resource restriction due to local conditions     |
|                     |                    |                                 | Available resources                              |
### Table 3
Modeling Parameters: Integrated

| Basis     | Objective function | Author                      | Constraints                                      |           |           | Others                |
|-----------|--------------------|-----------------------------|--------------------------------------------------|-----------|-----------|-----------------------|
|           |                    |                             | Capacity bounds                                  | Others    |           |                       |
| Time      | Transportation     | Wilson et al., (2013)       | Facility                                        | Task completion time | Location |                       |
|           | time               | 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 operations is categorized in 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     | Chen et al., (2011)           | Vehicle, Link Demand, supply Maintain the balance of in-flow and out-flow at each node |
|               | Time               | Yuan and Wang, (2009)         | - Supply, delivery, demand 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          |
|               | 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          | Relocation /       | Davis et al., (2013)          | Facility Supply quantity, time and demand Flow balance |
|               | Allocation cost    | 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              |
### Table 6

**Modeling Parameters: Integrated**

| Basis                  | Objective function | Author                      | Constraints                                                                 |
|------------------------|--------------------|-----------------------------|----------------------------------------------------------------------------|
| **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                                          |
|                       | Ozdamar, (2011)        | -                          | Unmet demand, commodities, total supply                                    |
|                       | Mete and Zabinsky, (2010) | Vehicle, facility         | Unsatisfied demand, medical supply                                         |
|                       | Van Hentenryck et al., (2010) | Vehicle                   | costs                                                                       |
|                       |                     |                             | Vehicules start and end locations                                          |
| **Loading, unloading Time** | Safeer et al., (2014)   | Vehicle, facility          | Supply Quantity, Demand, Capacity                                          |
|                       | Ozdamar, (2011)        | -                          | Unmet demand, commodities, total supply                                    |

**Authors:** Edrissi et al., (2013) - Noyan, (2012) - Ji and Zhu, (2012) - Duran et al., (2011) - Sheu et al., (2005) - Ji and Zhu, (2012) - Sheu, (2007) - Zhang et al., (2012) - Fiedrich et al., (2000) - Balcik and Beamon, (2008) - Brotcorne et al., (2003) - Brown and Vassillou, (1993) - Paul and Hariharan, (2012) - Ozdamar, (2011) - Horner and Widener, (2011) - Rath and Gutjahr, (2011) - Abounacer et al., (2014) - Safeer et al., (2014) - Van Hentenryck et al., (2010) - Mete and Zabinsky, (2010) - Ozdamar, (2011)
| Quantity | Unmet demand | Abounacer et al., (2014) | Vehicle, link | supply quantity, total working time, delivery | - |
|----------|--------------|--------------------------|----------------|-----------------------------------------------|---|
|          | Afshar and Haghani, (2012) | Vehicle, facility | Commodity flow, 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 | - |
|          | 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 increase proportionately with time. This calls for quick response in providing relief and shelter in order to minimize the loss.

Another research direction is developing a novel basis for relief distribution in 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. Which minimizes the 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 need 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 of accommodating more uncertainty and dynamic situations. The uncertainties mentioned include variations in demand, supply, availability of resources (relief items, vehicle, trained workers etc.), whereas dynamic 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 more tasks 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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