Post-Disaster Relief Distribution Using a Two Phase Bounded Heuristic Approach

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Post-Disaster Relief Distribution Using a Two Phase Bounded Heuristic Approach

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***Abstract*—Relief logistics distribution to disaster affected areas is crucial that needs quick and effective action. Logistics distribution through an efficient method is essential for easing the impact of the disaster in the affected areas. Disaster is non-deterministic, highly composite and uncertain in nature, therefore, the relief logistics distribution becomes a challenging task. Relief items can be distributed either from a single node or from multiple distributed nodes. Resources available at distributed nodes are not utilized when only single node logistics distribution is used. This paper presents a two-phase bounded heuristic approach for logistics distribution as a response to the post-disaster relief operation. The proposed approach is focused on two major objectives: minimization of unmet demand and travel distance. Simulated disaster scenario is synthesized as a case study for the distribution of relief items. The results indicate that the proposed approach is effective in logistic scheduling. It improves the relief logistics distribution systems in the disasters affected areas by utilizing the resources available at distributed nodes hence leads to decline in unmet demands level with minimum travel time.**

Keywords: ***Disaster; Logistic distribution; Heuristic search; Relief item class*.**

1. Introduction

Disaster is usually a breakdown in the normal functioning of nature that has a significant adverse impact on people, their works, and the environment. Relief operations such as relief logistics distribution, medical response, and injured people evacuation are required. All these operations have a common aim to aid people in their survival [1]. Relief logistics distribution has to react promptly to unanticipated changes in the disaster environment. When the disaster occurs, the logistics are intended for victimized people to enhance their lifestyle [2, 4].

According to Federal Emergency Management Agency, FEMA, (2004), Disaster Operations Management (DOM) [15] life cycle is divided into four main phases: mitigation, preparedness, response, and recovery. Mitigation is the effort to reduce the loss of life and property by lessening the impact of disasters. Preparedness within the field of emergency management can best be defined as a state of readiness to respond to a disaster. Response deals with how to respond to a crisis and recovery deals with after an emergency. By being able to act responsibly, early and safely, the chances of survival increases in an emergency. During the recovery period, all actions must take care of victims. Relief logistics distributions need to be effective, timely and economized supply of all the resources in all phases. The distribution must handle volume flexibility, delivery flexibility, and supply system flexibility for effective and efficient management [3]. A critical and challenging component of relief logistics distribution is the allocation of goods to beneficiaries [12, 13].

The major objectives and constraints are to minimize cost, unsatisfied demand, travel time, and rational relief distribution. Satisfying these objectives are the major challenges. There are also some constraints that make the job complex. Some of the very commonly faced constraints are stochastic supply and demand, resource availability, and vehicles routes. When relief logistics are distributed from supply to demand nodes, these resources have not been fully utilized using a single node distribution strategy. Using single node distribution strategy, all the loads from demand nodes are accumulated to the single supply node. There occurs unmet demand because of the limitation of the resources available at the single node even though spare resources are available at other distributed nodes. In the disasters scenarios, strategies are built based on the available information. Heuristic search provides solution towards the goal based on the available information.

The purpose of this research is to propose a strategy for relief logistics distribution as a post-disaster activity using two-phase bounded heuristic search. It incorporates more than one supply nodes. Incorporating distributed nodes, there occur maximization in the utilization of available resources and minimization in unmet demand level. The approach also classified supply nodes into bounded and unbounded nodes based on the availability and unavailability of resources respectively. Classifying the nodes provides pruning flexibility during the search for supply nodes. The major contribution of this paper is an approach that maximizes relief logistic distribution to the disaster area by decomposing the demand loads and distributing from different supply nodes based on minimum travel distance. Doing so unmet demand (deficit penalty) minimizes, which is one of the primary focus in disaster relief operations [14].

Rest of the paper is organized as follows: Section 2 presents a review of similar approaches logistic and methods applied for logistic distribution. Section 3 discusses the problems associated with the logistic distribution task. In section 4, overall solution strategies are conferred. Section 5 demonstrates a computational experiment of a disaster scenario and hence evaluating the performance of the proposed approach and concluding remarks and direction of future works are discussed in Section 6.

2. Related Work

Several approaches have been applied with the major objective of distribution logistics to disaster regions. Lin et al. [5] assumed a single centralized location for delivery of relief items with multiple disaster nodes dispersed geographically. All those nodes were assigned to a central depot for serving. Decomposition and Assignment Heuristic approach was used to deliver items to the disaster nodes. Rawls et al. [6] assumed pre-positioned storage house with three commodities for emergency supplies. A heuristic algorithm referred as Lagrangian L-Shaped Method was applied that decomposed the problem into series of sub-problems.

Pre-positioning of supplies at strategic locations is required so that relief commodities are available when needed [6, 11]. Developing an effective pre-positioning of resource nodes is challenging because of the uncertainty of occurrence of a disaster and its magnitude. Balcik et al. [7] proposed a model with a number of local distribution centers for relief supplies to the disaster victims based on supply. They considered two types of demand items, type-1 demands within a short period of time and type-2 demands occurs periodically, based on demand characteristics. Camacho-Vallejo et al. [9] applied a bi-level mathematical programming model where the problem was modeled with two different levels of pre-set hierarchy for decision-making to get optimum result in relief distribution. The model assumed a decision-maker at the upper level defined as the leader and at the lower level defined as the follower with a set of variables, constraints and corresponding objective functions at each level. The leader made decisions based on the action and the follower reacts accordingly. Lin et al. [8] applied the concept of temporary depots where the temporary depots were located in the disaster regions. Relief items were transferred to the temporary depots and disaster regions received relief items from assigned temporary depots.

3. Problem Statement

Relief-demand management is a prerequisite in any relief distribution. The relief logistics distribution plan for a disaster-affected region starts immediately once a disaster has occurred. There can be multiple supply centers with the dissimilar amount of relief items located at diverse regions. Central (Primary) supply node has higher capacity and is fully functional whereas disseminated (supplementary) supply nodes have lower capacity and have limited function. These supply nodes deliver relief items to the demand nodes.

Distribution of relief logistics from supply nodes to demand nodes is strategically a major issue at the tactical level of planning during disaster relief action. Population characteristics and pre-existing regional infrastructure in many disaster-prone areas may not be readily available, and the extent of post-disaster infrastructure damage may not be predictable [10]. An effective resource distribution strategy is required for relief distribution from supply nodes to the demand nodes. Logistics needs of the demand nodes are circulated by the supply nodes. Demand nodes are linked either to a central node or to the nearest secondary node as shown in Figure 1.This is a synthesized disaster case which is used as our case study to assess the effectiveness of the proposed approach of logistic circulation in two phases. The synthesized scenario is similar to the real case scenarios used as case study in other research [10, 15]. After Phase-I, nodes with spare resources are marked as bounded nodes and nodes without spare resources are marked as unbounded nodes. Hence, nodes are categorized into bounded and unbounded nodes. Supply node with full functional control and higher storage capacity is defined as a primary (central) node. Other supply nodes with limited functional control and with low or only specific storage capacity, are considered as supplementary nodes.

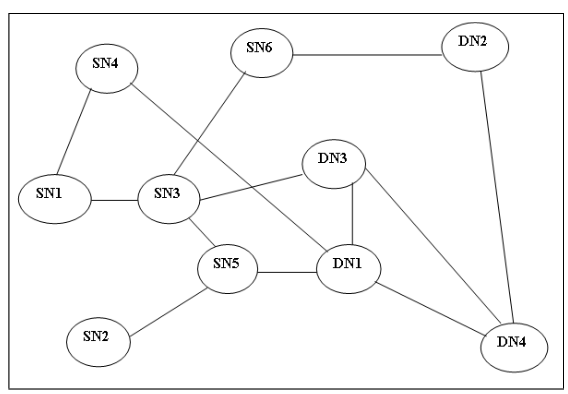

Figure 1. A synthesized disaster scenarios with supply and demand nodes connected by transportation link.(SN: supply Nodes, DN: Demand Nodes)

When a single central distribution node is used, all the demand loads are assigned to the central node only. Logistics available at the central node may not be enough to meet the demand. Unused relief items available at secondary storage area are not being fully utilized in most of the cases because of incompetent strategies.Unutilized resources available at the secondary locations can be utilized to meet the demand. Maximizing utilization of available resource i.e. minimizing unmet demand (deficit penalty) is vital in the post-disaster relief distribution cases.

We propose an approach for relief circulation with distributed and decomposed supply strategy based on heuristic search. Few assumptions are made for this strategy.

i. No restriction on the number of vehicles available for logistic transport from supply nodes to disaster nodes. We also do not consider vehicles capacity.
ii. Locations of primary and secondary supply nodes are static and known.
iii. Items stored at supply nodes are within maximum storing capacity.

Considering these assumptions, the strategy is aimed for effective logistic distribution. We consider three main components. The first component is set of *Nodes* N_i, N_i is either *Demand Nodes,* D_j or *Supply Nodes,* S_k. Second component is set of *Resource Classes* R_i. $\{R_a, R_b, R_c\}$ resources are classified based on their usability. Requirement of R_i varies from one N_i to another N_j where i $\neq j$. Each R_i travels from S_k to D_j. The third component is set of *Connecting Arcs,* A_i. We consider effective travel time from one node, i to another node, j, as a *Distance Measure,* d_{ij}. $Y_{R_j}^{D_j}$ is the *Resource Demand* R_i at *Demand Node* D_j. $Z_{R_j}^{S_k}$ is the *Available Resource* R_i at *Supply Node Node* D_j. $X_{R_i}^{S_k D_j}$ is the *Resource Supplied* from S_k to D_j of *Resource Class* R_i.

We set two objective functions in this proposed approach.

Objective Function:

Maximize:

i. $\sum_i \sum_j (Y_{R_j}^{D_j} - X_{R_i}^{S_k D_j})$
ii. $\sum_i \sum_j (d_{ij})$

Subject to:

i. $\sum_j X_{R_i}^{S_k D_j} \leq Z_{R_j}^{S_k}$
ii. $\sum_k X_{R_i}^{S_k D_j} \leq Y_{R_j}^{D_j}$
iii. Stored item at each $S_k \leq$ Maximum storing capacity
iv. Each D_j must be assigned to at least one S_k
v. Transportation only via available links

4. Proposed Solution Strategy

In the proposed system, we considered distributed supply nodes in order to develop an effective method for relief logistics distribution. Logistic needs vary from node to node. Demands are decomposed into item classes. Each class is treated individually. The demand of any disaster node can be fulfilled from more than one supply nodes. Classification of relief items is according to their use and nature.

4.1. Demand Characterization

Logistic needs after a disaster are not uniform at demand locations and also are diverse in nature. Logistic items during the relief distribution are characterized based on their usability. We broadly categorized these items into three classes. Class-1 (R_a) items are frequent items for which demand occurs regularly and periodically. Items like food, water are classified under this class. Class-2 R_b items are semi-frequent items for which demands occurs not as frequent as class-1. They are not very common and non-periodic. Items like medicine, hygiene kits are grouped under this class. Class-3 R_b items are supplementary items for which demand is high at an early stage of disaster and decreases with the time. Items such as clothes, tents, blankets are classified under this class.

Bounded heuristic search is applied for relief logistics distribution strategy. Search ignores the unbounded nodes for distribution. The distribution approach is applied in two phases. Identification of nearest serving nodes and hence calculation of demand load and deficit load are applied in Phase-I. Decomposition of load and applying of bounded heuristic search to find next nearest serving nodes for each class of items are applied in Phase-II..

4.2. Heuristic Algorithm

Early transfer of logistic to disaster-hit regions in any disaster response is the primary objective. Therefore assigning the nearest supply nodes with an available resource for relief item circulation is an effective tactic in any disaster scenario.

Phase-I: Node assign and migration

Phase-I is mainly focused on assigning and migration of disaster nodes. Each disaster nodes are assigned to the corresponding nearest supply nodes. Migration of demand node from one supply node to either next nearest supply nodes or to the central node is applied. In any case, if the demand is higher than available resource at that supplementary node, the supplementary node is assigned to the nearest node and remaining demand is migrated to the next nearest node. Iteratively, all demands nodes are assigned to one serving node as described in pseudocode for Phase-I. This phase supports in assigning demand nodes to the nearest supply nodes that assure the early transfer of relief from the nearest supply nodes..

[**Phase-I: Node assign and migration**]

Pseudocode-1

Define: D_j: Demand Nodes, S_k: Supply Nodes, Y: Demand Load, Z: Available Resources, Resource Class: R_a, R_b, R_c

```
Read List of D_j and S_k
while i ≤ n do
    find-nearest-supply-nodes (i)
    assign (S_k)
end while
Iterate:
while i ≤ n do
    if (S_k connected to D_j) = Yes then
        Y(S_k) = calculate-demand-load (S_k)
    else
        Y(S_k) = 0
        while Y < Z or next-nearest-node is primary-node do
            if (connected-node > 1) then
                migrate-to-next-nearest(S_k)
```

Total demand cannot be fulfilled by applying distribution from a central node only as shown in Table 4.It shows that there occurs unmet demand after Phase-I. This specifies that there is deficit amount in supply even though there is the availability of resources at other supply nodes. Supplementary supply nodes located at distributed locations with resources can be used for distribution.

Distributed and decomposed approach of logistic distribution is applied in Phase-II. Unused resources at central and supplementary nodes are distributed to demand nodes by applying bounded heuristic search. Each class of resource demand is treated individually and circulated from the supply nodes to demand nodes based on minimization of total travel distance. Travel distance in terms of effective travel time is calculated based on the length of connecting link and the vehicle speed. Searching starts from the first node in the search sequence set and proceeds to the next node until the last node is reached. Algorithm search only bounded nodes for resource distribution. Use of bounded node applies as pruning in the search by ignoring the unbounded nodes. Individual demand nodes are assigned with corresponding nearest bounded nodes for distribution with required relief items for each class of resources. Iteratively, the search checks for each demand node requirements and supply nodes resource availability. The total travel time of each distribution sequence is calculated. Distribution sequence based on minimum travel time is selected for distribution of resources as described in pseudocode for Phase-II.

[**Phase-II: Load Distribution and Decomposition**]

Pseudocode-2

Generate 25% random search sequence of supply nodes

```
Search from sequence 1 to n
while i ≤ n do
    for i = 1 to n sequence
    for j = 1 to all resources class
    for k = start node to end node in the sequence
    if (Z_j > 0) then
        set node-status = bounded
    else
        set node-status = unbounded

        for m = 1 to all bounded node
        find-nearest (D_j)
        D_j-status = check (is-required(R_j))
        if D_j-status = yes then
            update-supply-status()
            update-travel-distance()
        else
            find-next-nearest (D_j)

            for i = 0 to n sequence
            find(minimum-distance -sequence)
            Distribution = minimum-distance-sequence(supply-status)
```

---

5. Experimental results and analysis

The main purpose of the simulation is to demonstrate the efficiency of the proposed approach. It defines a heuristic approach with decomposed and distribution strategy for the relief in disaster scenarios. This also shows the possible benefits of implementing bounded distributed-supply approaches.

5.1. Case Study

Disaster regions have been considered along with their suffered populations. Each node has been connected directly or indirectly with transportation links, A_i. In this case, effective travel time from one node to another is considered as distance measure, d_{ij}. The scenario consists of one central (primary) node, S_1, and five supplementary (secondary) nodes, $(S_2 - S_6)$, as shown in Figure 1. Four disaster nodes, D_j, needs relief items from one or more than one supply nodes.

At the initial point, demand load is calculated based on the affected population status at disaster node and serving the capacity of each unit of resources. Table 1 shows

TABLE 1. Population and demand status of demand nodes.

Dj	Population	Resource (Ra)	Resource (Rb)	Resource (Rc)
1	20000	2000	1000	4000
2	2500	250	125	500
3	70000	7000	3500	14000
4	50000	5000	2500	10000

TABLE 2. Resource available at each supply nodes (class-wise) (p: primary, s: supplementary)

Sk	Resource (Ra)	Resource (Rb)	Resource (Rc)
1 (p)	10000	5000	20000
2 (s)	2000	500	10000
3 (s)	2000	1500	200
4 (s)	2000	2000	500
5 (s)	1000	1000	100
6 (s)	2000	100	15

resource demand of each disaster nodes. Table 2 shows the available resource status at different supply nodes of the synthesized scenario of disaster.

When Phase- I algorithm is applied, it first assigns each disaster node to the nearest supply nodes. Demand load is calculated for each serving nodes. If resources available at secondary nodes are less than the demand at that node, migration of nodes is applied which leads to the transfer of demand to either the next nearest supply node or to the central node. Migration of nodes is applied iteratively.

At the end of Phase-I, deficit penalty (unmet demand) along with resource available at central node and supplementary nodes are calculated as shown in Table 3. Phase-II generates a random sequence of serving nodes for heuristic search. Pruning is applied by means of applying search only to the bounded nodes. Implementation of node pruning in terms of bounded node decrease the search space.

In one run all search sequence is executed and also

TABLE 3. Summary of resource status after Phase-I

After Phase-I	Resource (Ra)	Resource (Rb)	Resource (Rc)
Demand (Total)	14250	7125	28500
Supply	8250	5100	10315
Unmet (Deficit Penalty)	6000	2025	18185
Resource Available at Master Node	5000	2500	10000
Resource Available at Supplementary Node	5750	2500	10500

TABLE 4. Sample random sequence of supply nodes for distribution

Sequence	node	node	node	node	node	node
1	2	1	6	3	4	5
2	5	3	2	6	4	1

TABLE 5. Resource distribution status after phase-II

Dj	Resource	Supply Node (Sk)					
		1	2	3	4	5	6
1	Ra	-	1000	-	-	-	-
	Rb	-	-	-	-	-	-
	Rc	-	3900	-	-	-	-
2	Ra	-	-	-	-	-	-
	Rb	25	-	-	-	-	-
	Rc	-	485	-	-	-	-
3	Ra	3250	-	-	-	-	1750
	Rb	-	2000	-	-	-	-
	Rc	10000	3800	-	-	-	-
4	Ra	-	-	-	-	-	-
	Rb	-	-	-	-	-	-
	Rc	-	-	-	-	-	-

total travel time is calculated for each sequence. The sequence with minimum total travel distance is selected for distribution sequence as shown in table 5. After Phase-II implementation, it is also observed that demands of different nodes are fulfilled and minimized as shown in Figure 2, 3 and 4. By applying distributed supply nodes, requirements of each node are satisfied that leads to minimization in unmet demand.

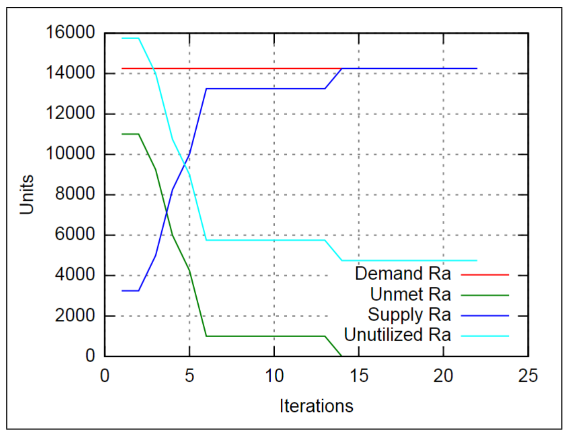

Figure 2. Plot of resource Ra status

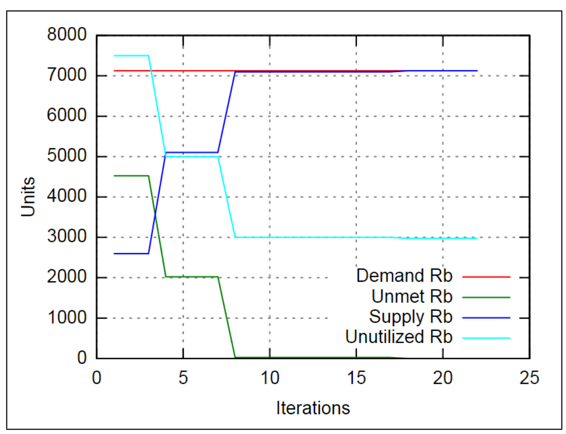

Figure 3. Plot of resource Rb status

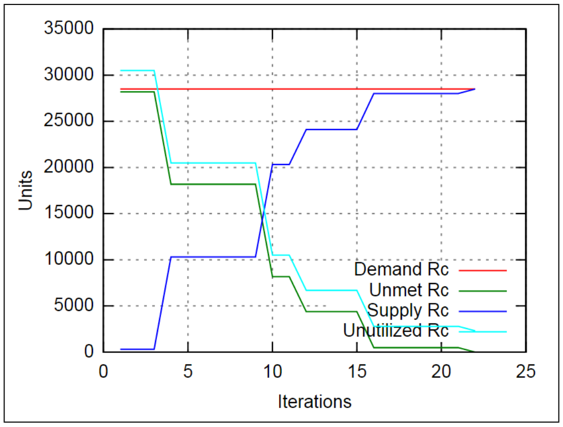

Figure 4. Plot of resource Rc status

5.2. Analysis of distributed approach

The empirical evaluation shows that bounded heuristic approach for logistic circulation has improved relief distribution performance over centralized approach. Deficit penalty minimization is one of the prime objectives in disaster relief distribution. Applying distributed approach shows an increase in utilization of available resources at those locations and minimization of deficit penalty. In disaster scenarios, meeting demand requirements timely is more crucial, though supplying resources from other supplementary nodes increase the travel distance. This advocates that there is a trade-off between travel distance and deficit penalty minimization. Considering the effectiveness and impact, bounded distribution strategy of relief items is effective in disaster scenarios.

6. Conclusion and future works

An effective strategy is required in relief item circulation in disaster scenarios. Use of distributed supply nodes instead of centralized supply node improves the relief logistics distribution from supply nodes to disaster nodes. Utilization of unused resources available at supplementary nodes implies minimization of deficit penalty. The deficit penalty is minimized and dropped to zero when distributed supplementary nodes are used. In this research, we proposed bounded heuristic search methods for relief item circulation that applies pruning as well by escaping the unbounded nodes. Pruning using bounded concept enhance the searching of supply nodes for distribution.

Logistic distribution in disaster scenarios is complex. Investigation on the robustness of proposed approach with respect to uncertainty in demand, transportation link is vital. Consideration of transportation link conditions and capacity will enhance the efficiency in distribution plan. By considering individual disaster nodes priority and item class priority will make the distribution strategy even more effective.

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