Budget-constrained pre-positioning of emergency relief supplies to minimize unmet demand

Renata Turkeš, Daniel Palhazi Cuervo, Kenneth Sörensen
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In just over a decade, the number of people in need of aid has more than doubled. At the beginning of 2015 we were aiming to assist 57.5 million people in 22 countries needing assistance.
Motivation

IRAQ

8.2M PEOPLE IN NEED OF ASSISTANCE
60% OF FRONTLINE HUMANITARIAN OPERATIONS AT RISK OF SHUTTING DOWN DUE TO UNDERFUNDING
Motivation

SYRIA

4M FORCED ACROSS BORDERS
4.8M PEOPLE LIVING IN HARD-TO-REACH OR BESIEGED LOCATIONS
Motivation

YEMEN

21.4M PEOPLE IN DIRE NEED OF ASSISTANCE
20.4M PEOPLE NEED ACCESS TO CLEAN WATER AND SANITATION
Motivation

UKRAINE

5M IN NEED OF HUMANITARIAN ASSISTANCE
2.2M UPROOTED BY CONFLICT
In the **SAHEL** alone

**9 million**

women, children and men will go hungry this year if aid doesn't reach them.
Motivation

$20.1\text{ BILLION TO PROVIDE AID TO 87.6 MILLION PEOPLE IN 2016}$
Problem description

Humanitarian logistics

The objective of disaster response in the humanitarian relief chain is to rapidly provide relief (emergency food, water, medicine, shelter, and supplies) to areas affected by large-scale emergencies, so as to minimize human suffering and death. [1]

⇒ Optimization problem!
Problem description
The related academic literature in humanitarian logistics mostly falls into one of the three streams:

- Facility location
- Inventory management
- Routing
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Pre-positioning of emergency supplies for disaster response

Develop emergency response pre-positioning strategy that determines

▶ number, location and size of storage facilities
▶ quantities of various types of emergency supplies stocked in each facility
▶ (distribution of the supplies to demand locations after an event,)

under uncertainty about if, or where, a natural disaster will occur.

This problem is NP-hard, as a generalization of facility location problem and VRP, that are NP-hard.
Problem description: Example

Scenario 1, $p_1 = 0.9$

Scenario 2, $p_2 = 0.1$
Literature review: Possible drawbacks

- Only the problem of post-disaster aid distribution is considered.
- The pre-positioning problem is considered, but
  - one or more of the decisions (location, inventory, distribution) is missing
  - uncertainty is not considered
  - some simplifying unrealistic assumptions are made
  - poor choice of objective function
  - algorithm tested on one instance only
  - problem is solved only using a commercial solver
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Literature review: Rawls-Turnquist

\[
\min \sum_{i \in V} \sum_{l \in L} F_{iyil} + \sum_{k \in K} \sum_{i \in I} q_k r_{ik} + \sum_{s \in S} p_s \left[ \sum_{(i,j) \in E} \sum_{k \in K} c_{ijks} x_{ijks} + \sum_{i \in V} \sum_{k \in K} (h_k z_{iks} + u_k w_{iks}) \right],
\]

subject to facility capacity, flow conservation and arc capacity constraints.
Literature review: Rawls-Turnquist

Poor choice of objective function value, as it is:

- Minimizing costs, what is more suitable in business logistics
- The goal of the pre-positioning strategies (that inevitably increase the costs)
- Difficult to determine the weights
- Putting a price on human life
- Allowing that the available budget is not fully used, meeting less demand than what would be possible otherwise
- Allowing that the minimal costs significantly exceed the available budget
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The relationship between the unmet demand penalty factor and the objective function value (on a small instance), for holding factor = 0.25.
The relationship between the unmet demand penalty factor and the objective function value (on a small instance), for holding factor = 10.
The objective is to minimize

- expected unmet demand
- expected response times
- expected spoilage cost

in lexicographic order, such that the cost of opening the facilities, acquisition cost, and transportation cost respect their budget limitations (and the other capacity constraints are satisfied).
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max \sum_{s \in S} p_s \sum_{f \in V} \sum_{i \in V} d_{is} x_{fis}

such that the cost of opening the facilities, acquisition cost and transportation cost respect their budget limitations (and other capacity constraints are satisfied).
Algorithm 1: Matheuristic

Data: Input data: Instance
Result: Output data: Solution

CurrentSolution = EmptySolution(Instance);
for $t=0$ to NumberOfInitialSolutions do
    TempSolution = GreedyRandConstHeuristic(CurrentSolution);
    if TempSolution is better than CurrentSolution then
        CurrentSolution = TempSolution;
    end
end
CurrentSolution = LocalSearch(CurrentSolution);
return CurrentSolution
A case study focused on hurricane threat in the southeastern area of the United States (30 cities, 58 arcs, 3 commodities, 3 facility sizes, 51 scenario).

<table>
<thead>
<tr>
<th></th>
<th>optimal solution*</th>
<th>matheuristic**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmet demand (%)</td>
<td>13.0616</td>
<td>13.2865</td>
</tr>
<tr>
<td>Computation time (s)</td>
<td>5112</td>
<td>28</td>
</tr>
</tbody>
</table>

* MIP optimality gap = 1.13 %
** average over 5 runs
The objective in the formulation of humanitarian logistics problems should be to minimize unmet demand and response time, instead of costs. Real-world problem formulations should avoid oversimplifications; heuristics are more suitable to deal with the complexity of the realistic instances.
Concluding remarks

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References


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