Humanitarian Supply Chain Network Models for Disaster Relief

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Presentation Outline

Humanitarian Logistics for Disaster Relief

Aim: Get relief aid to victims as fast as possible.

Much interest: Balcik et al. (2008), Van Wassenhove and Pedraza Martinez (2010), Vitoriano et al. (2011), and many others.

Amidst great uncertainty, decide:

- who (multiple agencies)
- sends what (relief items, transport resources, ...)
- where (recipients, warehouses, ...)
- over which routes (if open)
- over a "planning horizon" (if definable)
- in order to meet "demand" (if known or predictable)
  . . . or rather, alleviate unmet need
- at fast as possible (and efficiently)

Basic (Deterministic) Network Model

Indices

i, j, k Items,
e.g., food, shelter, health supplies, ...

r Transport resource types,
e.g., trucks, helicopters, aircraft, ...

n, m Nodes in the relief supply chain,
including the locations of needy recipients.

N Network arcs $n \to m$ in the supply chain.

t Time period in the planning horizon,
e.g., days or 4-hour-blocks.

Input Data too much? too uncertain?

- b_{int} Incoming supplies of item i at node n by end of period t.
- d_{int} Demand for item i at node n at end of period t.
- w_{in} Weighting (urgency) to meet demand for item i at node n.
- AvI_{in1} Current inventory of product i at node n.
- UnD_{in1} Current unmet demand for item i at node n.
- AvR_{in1} Current availability of transport resource r at node n.
- c_{ir} Amount of resource r that can transport one unit of item i. Assume just one resource r is sufficient.
- L_{rnm} Lead time to transport any item by resource r on network arc $n \rightarrow m$.

Decisions too many?

AvI_{int}	Available inventory of item i at node n at start of period t.
UnD_{int}	Accumulated unmet demand/need) of item i at node n at start of period t, non-negative.
x_{irnmt}	Quantity of item i transported by resource r on arc $n \to m$ leaving at start of period t.
y_{rnmt}	Quantity of transport resource r sent on network arc $n \to m$ at start of period t.
AvR_{rnt}	Availability of transport resource type r at node n at start of period t.
a_{irnt}	Allocation to item i of transport resource r at node n at start of period t.
UnR_{rnt}	Unused transport resource r after allocating the rest of AvR_{rnt} at node n at start of period t.

Objective function & Flow of transport resources

Prioritize meeting unmet need (recipient demand), avoiding excessive inventory:

$$\text{Minimise} \quad \sum_{i,n,t} w_{in} \left(UnD_{int} + 0.001 Av_{int} \right) \tag{1}$$

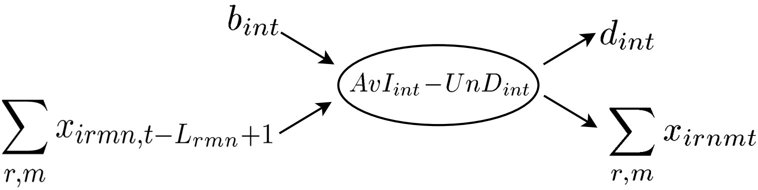
Balance the inventory and flow of transport resources over consecutive periods at each network node:

$$\sum_{m} y_{rmn,t-L_{rmn}+1} \longrightarrow \boxed{AvR_{rnt}} \longrightarrow \sum_{m} y_{rnmt}$$

$$AvR_{rnt} + \sum_{m} y_{rmn,t-L_{rmn}+1} - \sum_{m} y_{rnmt} = AvR_{rn,t+1} \qquad \forall\, r,\ n,\ t \tag{2}$$

Flow of relief items

Balance inventory, unmet demand, the flow of items and recipient demand over consecutive periods at each network node:



$$AvI_{int} - UnD_{int} + b_{int} + \sum_{r,m} x_{irmn,t-L_{rmn}+1} - d_{int} - \sum_{r,m} x_{irnmt}$$
$$= AvI_{in,t+1} - UnD_{in,t+1} \qquad \forall\, i,\ n,\ t \tag{3}$$

Management of transport resources

Allocate resources to transport the items:

$$a_{irnt} = c_{ir} \sum_{m} x_{irnmt} \qquad \forall\, i,\ r,\ n,\ t \tag{4}$$

Link flow of transportation resources with their allocation to items:

$$\sum_{m} y_{rnmt} = \sum_{i} a_{irnt} \qquad \forall\, r,\ n,\ t \tag{5}$$

No more transport to be used than is available, and calculate unused resources:

$$\sum_{m} y_{rnmt} + UnR_{rnt} = AvR_{rnt} \qquad \forall\, r,\ n,\ t \tag{6}$$

Fleeing evacuees

Model can also represent the evacuation of victims
and the transport resources needed.

Represent evacuees as ”items” (just technically) :

Counter-flow opposite to the flow of relief supplies.

Availability” at the disaster nodes and

”Demand” at the relief-centre

Urgency of evacuation can be reflected by giving very high values to the evacuees’ urgency weighting w.

Robust Optimization Approach

Minimize the maximum weighted unmet demand (recipient needs) over the set S of different demand **scenarios**:

$$\min_{x,y}\{\max_{s\in S}\sum_{i,n,t} w_{in}\, UnD_{int}\} \tag{7}$$

i.e.,

$$\min Z + 0.001 \sum_{s,i,n,t} w_{in}\, UnD_{sint} \tag{8}$$

where

$$Z \ \geq \ \sum_{s,i,n,t} w_{in}\, UnD_{sint} \forall s \tag{9}$$

The last term $0.001 \sum \sum w\, UnD$ in (8) prevents individual values of UnD_{sint} being arbitrarily large.

Scenario Flow constraints

Revise item flow constraints, i,e,, for each scenario s:

$$AvI_{sint} - UnD_{sint} - \sum_{r,m} x_{irnmt} + \sum_{r,m} x_{irmn,t-L_r+1} + d_{sint} = AvI_{sin,t+1} - UnD_{sin,t+1} \quad \forall\ s,\ i,\ n,\ t \tag{10}$$

Two related questions pose themselves:

1. What is a reasonable set of demand scenarios?
2. Won't the use of objective function (8) simply provide solutions for the most pessimistic demand scenarios?

   This will waste resources in the most typical scenarios,

   and so could undermine the credibility of the model.

Likely and Unlikely Scenarios

So divide scenarios into two or more types:

- *Likely/Typical* scenarios are treated via mini-max (as above)
- *Possible/Unlikely* scenarios are represented by mean values in the objective function:

$$\min Z_{typical} + \left(\frac{Weight}{|Possible|}\right) \sum_{s \in Possible} \sum_{i,n,t} w_{in}\, UnD_{sint} + 0.001 \sum_{s \in Typical} \sum_{i,n,t} w_{in}\, UnD_{sint} \qquad (11)$$

Decision-makers may prefer instead to define reserves for possible/unlikely events.

Future research

Discounting future uncertainties and decisions

Decisions made now, but implemented further ahead in time, are subverted by more uncertainty.

So discount using the classical exponential smoothing constant α, revising the objective function:

$$\min Z_{typical} + \left(\frac{Weight}{|Possible|}\right) \sum_{s \in Possible} \sum_{i,n,t} \alpha^{t-1}(1-\alpha)\, w_{in}\, UnD_{sint}$$

$$+ 0.001 \sum_{s \in Typical} \sum_{i,n,t} w_{in}\, UnD_{sint} \quad (12)$$

The last term $0.001 \sum \sum w\, UnD$ in (12) is not discounted.
Also:

$$Z \geq \sum_{s,i,n,t} \alpha^{t-1}(1-\alpha)\, w_{in}\, UnD_{sint} \forall s \quad (13)$$

Reality: Multiple Sources of Uncertainty

Recipients:

- Where are they? At which nodes n?
- What is their "demand" d_{int} over time?

Transport:

- What networks links $n \to m$ are operational? With what flow capacity? Some may be partially blocked by fleeing evacuees.
- What transport resources AvR_{rn1} are available, where?
- Lead times L_{rnm} may be long, variable, ill-known.

External supplies:

- What i will be available when t?
- Where? (at which network node n?)
- How much is b_{int}?
- Local procurement possibilities for b_{int}?

Coping with multiple sources of uncertainty

Can we represent all uncertainties within the scenario sets?

Should the scenario sets contain

- just randomly-sampled points? (and many of them?)
- or a large sample of worst/best case combinations?
- or mix of the above?

Maybe *constraint sampling*

- constraints are obtained via Monte Carlo sampling of the uncertain parameters
- but not all original constraints may be satisfied.

Future research.

Multiple agencies often act without coordination

Strategically:

- Improve inter-agency communication
- Use enabling technologies (via the ”cloud”?).

Operationally, an agency’s use of the model:

- should include uncertain information about the actions of other agencies
- by including extra parameters that represent the impact of other agency’s actions.
- Example: forecast extra availability of relief items at certain nodes, or spare capacity, or other transport resources.

Represent within the scenario uncertainty sets?

Future research.

Replanning & Disruption

Replan with minimal disruption, while maintaining robustness:

$$\min_{x,y}\{\max_{s\in S}\sum_{i,n,t} w_{in}\, UnD_{int} + \text{Penalty} * \text{Disruption(Old}\rightarrow\text{New)}\}$$

Should we be concerned about disruption if it is a consequence of relieving need as quickly as possible?

What kind of disruption should be avoided?

Suppose demand changes location in such a manner that aid doubles back along an arc it has just traversed?

- Is this undesirable? (inefficient? embarrassing? bad press?)
- Or simply an unavoidable side-effect of great uncertainty?
- Could this be avoided via super-robust initial plans?
- Or via a tabu-type list?

Future research.

Conclusions, Reflections, and Future Research

Conclusion: Robust Optimization models

- must not be naïve: hostile environment for modelling
- unquantifiable uncertainty
  $\Rightarrow$ use judgement and define scenarios
- Classify scenarios: *Likely/Typical* and *Possible/Unlikely* to avoid overly-pessimistic decisions.
- Computationally viable models, applied on a rolling horizon basis with frequent replanning

Future Work:

- Validate model with users, then in the field
- Integrate with information systems
- Implement in the cloud for operational use?

References

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