UCM-HUMLOG

Research Group on
Decision Aid Models for Logistics and Disaster Management
(Humanitarian Logistics)

Louvain, October 21\textsuperscript{st} 2021

www.mat.ucm.es/humlog

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Global Logistic Cluster
Complutense University of Madrid, Spain

- Public university
- The biggest university in Spain (~80,000 students), 3rd in Europe
- Strong relationships with Latin America
- Destination for students of many countries (Erasmus, China...)

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Faculty of Mathematical Sciences

- Biggest Faculty of Mathematics in Spain

- Highlights:
  - 3 departments
    - Algebra, Geometry and Topology
    - Mathematical Analysis and Applied Mathematics
    - Statistics and Operational Research
  - Applied orientation
  - Interdisciplinary Mathematics Institute (IM): Research Institute
  - Master in Disaster Management: joint with Technical University of Madrid.
    - 18 centres (energy, civil engineering, medicine, architecture, sociology, psychology, topography, physics, geology, telecommunications, nursing...)
UCM-HUMLOG: Decision Aid Models for Logistics and Disaster Management (*Humanitarian Logistics*)

- New decision aid models for logistics, especially disaster logistics
  - Working on humanitarian logistics problems since 2001
  - Last funding projects:
    - Decision Aid Models and Data Science in Disaster Logistics, Development and Sustainability (LOG4D). Spain
    - Optimization of Stock of Consumables in Transportation Companies. OBUU
    - Optimisation and Data Science for Staff Shifts. Mapal Software S.L.
- Test cases repository for Humanitarian Logistics models (academia)
- Cooperation for development since 1994 (Mozambique, El Salvador, Peru...)

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Research group, HUMLOG Decision Aid Models for Logistics and Disaster Management (Humanitarian Logistics): The group’s work is mainly devoted to the development of decision aid models in humanitarian logistics and disaster management, but also maintains activity in general logistics. The widest context for humanitarian logistics applications is disaster management but it also appears in other contexts, such as the case of humanitarian operations not linked to a specific disaster (WFP, vaccination campaigns) or development projects which is in disaster management where the application of humanitarian logistics is more specific, complex and difficult.


Warehouses location and prepositioning

Preparedness decisions with different time horizon:

- Strategic: warehouses location & sizing
- Tactical: prepositioning
- Operational: scenarios to be taken into account evaluating decisions

Model characteristics:

- GIS integration
- Scenario generation
- Multiobjective and stochastic optimization: unmet demand, deterministic and stochastic cost.
- Case studies: Mexico floods decisions in emergency; Mozambique preparedness

Rodríguez-Martínez, A., Vitoriano, B., Ortuño, M.T. (2018) A multistage stochastic optimization model for strategic facility location and tactical resources allocation for humanitarian logistics. EJGSC 0(00).


Different attributes: Cost, equity of distribution, priority of a location, time of response, reliability (state of roads), security

Building realistic test cases: difficult but very important task to validate models and to be useful for involved organizations

Different versions:
- Simplified: double flow
- Dynamic: explicit control of timing and vehicle routes
- For unsafe environments: scheduling of vehicles, that travel together in convoys for security reasons

HADS: Distribution of Humanitarian Aid

Response

Preparedness & Early Response

SEDN: Assessment of disaster consequences

Just when a disaster strikes:
- Uncertainty about what’s happening;
- Urgent strategic decisions to be taken.

Cost, equity of distribution, priority of a location, time of response, reliability (state of roads), security

Human evacuation

Evacuation of people from affected areas to safe places and distribution of basic necessities

Characteristics of the model:
- Multiple criteria
- Joint human evacuation and commodities distribution
- Consideration of the gravity of the affected people

Resolution: Lexicographical goal programming with two priority levels:
1. Evacuation time of people in a critical state
2. Total evacuation time & operational cost


Transportation, Energy, Production...

Green vehicles networks design
Power generation planning
Railway transport
Agriculture/Farm planning
Ortegrering problems
Safety and Security
Reliability

- Development of models for companies/institutions over time:
- Integration with internal systems to support decision making
- Based on Optimisation:
- Special treatment of uncertainty (fuzzy, stochastic programming...)
- Including data science for better decision making


General Logistics

Decision Aid Models and Data Science for Staff Shifts

- Development of models for companies/institutions over time:
- Integration with internal systems to support decision making
- Based on Optimisation:
- Special treatment of uncertainty (fuzzy, stochastic programming...)
- Including data science for better decision making


Resources management for emergency services

Case Study: Preparedness for long term staff scheduling pre-disaster, and modification after disaster strikes minimizing the deviation to the schedule (disruption management)

Model characteristics:
- Multiple criteria
- Uncertainty
- Using historical risk assessment data

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**HADS: Distribution of Humanitarian Aid**

Different attributes: Cost, equity of distribution, priority of a location, time of response, reliability (state of roads), security

Realistic test cases: difficult but very important task to validate models and to be useful for involved organizations

Different versions:
- **Simplified**: double network flow
- **Dynamic**: explicit control of timing and vehicle routes
- **For unsafe environments**: scheduling of vehicles travelling together in convoys for security reasons

**Case Study: Haiti Earthquake 2010**

- Ferrer, J.M., Ortuño, M.T., Tirado G. (2020) A New Ant Colony-Based Methodology for Disaster Relief, Mathematics, 8(4), 518

**Case Study: Pakistan Floods 2010**

- - Ferrer, J.M., Ortuño, M.T., Tirado G. (2020) A New Ant Colony-Based Methodology for Disaster Relief, Mathematics, 8(4), 518

**Human evacuation**

Evacuation of people from affected areas to safe places and distribution of basic commodities

Emergencia en el Salvador, Cesal.org

**Model characteristics:**
- Multiple criteria
- Joint human evacuation and commodities distribution
- Considering gravity of the affected people

- Flores, I., Ortuño, M.T., Tirado, G., Vitoriano, B. (2020) Supported Evacuation for Disaster Relief through Lexicographical Goal Programming, Mathematics 8, 648

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**SEDD: Assessment of disaster consequences**

Just when a disaster strikes:
- uncertainty about what’s happening;
- urgent strategic decisions to be made.

Disaster consequences $\rightarrow$ needs of the affected population $\rightarrow$ requirements of relief operations

**FUZZY BIPOLAR CLASSIFICATION**

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**Warehouses location and prepositioning**

Preparedness decisions for different time horizon:
- **Strategic**: warehouses location & sizing
- **Tactical**: prepositioning, yearly budget
- **Operational**: future scenarios to be considered for evaluating decisions

**Model features**
- Scenarios generation
- Multiobjective and stochastic optimization: unmet demand, deterministic and stochastic cost.
- GIS integration
- Case studies: Mexico floods decisions in emergency; Mozambique preparedness


[Case Study: Mozambique](http://www.mat.ucm.es/humlog)
Warehouses location and prepositioning

- When a disaster strikes a community, first moments are critical saving lives and big amounts of relief aid must be moved to provide it to the affected population.
- First responders: population, civil protection, governments, NGO in the country.
- International support will arrive with delay. Local capacities are critical to response (first 72 hours).
- Logistics is critical to provide relief at right time, right place, right amount, right quality, right cost, right source (the six “rights”)
- Humanitarian logistics activities extend over time: from preparedness to response and recovery.
# Humanitarian logistics

<table>
<thead>
<tr>
<th></th>
<th>Assessment &amp; planning</th>
<th>Procurement</th>
<th>Warehousing</th>
<th>Transportation</th>
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<tr>
<td><strong>Strategic decisions</strong> (&gt;2 years)</td>
<td>Strategic planning</td>
<td>Long term agreements, Standard definitions</td>
<td>Planning capacity, Warehouses (location)</td>
<td>Planning strategy, transport capacity and network</td>
</tr>
<tr>
<td><strong>Tactical decisions</strong> (6 ms.-2y/s)</td>
<td>Planning demand, activities, standard equipment</td>
<td>Procurement methods, <strong>advanced procurement</strong></td>
<td>Planning prepositioning &amp; management</td>
<td>Planning modes and transportation routes</td>
</tr>
<tr>
<td><strong>Operational decisions</strong> (&lt; 6 months)</td>
<td>Damage &amp; needs assessment, local capacities assessment, launch SAR, deployment of teams</td>
<td>Acquisition, <strong>consolidate orders, new orders</strong>, defining standard and kits, agreements</td>
<td>Managing goods, preparing kits, control of inflows and outflows, location on the field</td>
<td>Transport primary (point to point) and secondary movements (to several EDPs or warehouses on the field). Customs</td>
</tr>
</tbody>
</table>
Preparedness model

Local entities: humanitarian aid prepositioned

– Strategic decisions (unique for different scenarios):
  • When and where to locate the main warehouses?
  • What does their capacities have to?

– Tactical decisions (unique for different scenarios):
  • How much humanitarian aid to be prepositioned?
  • Where to locate the prepositioned aid?
  • What budget should be saved for facilities and for response?

– Operational decisions (for each scenario):
  • How transport the goods to be distributed?
  • How much relief aid to be acquired in emergency?
  • How much relief aid to be acquired to restore stock levels?

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Preparedness model

Model for strategic and tactical decisions taking into account operational decisions under different scenarios

– Time horizon: several years
– Stages: each year (e)
– Periods: each season into a year (t)
– Transport network: Nodes (demand, supply, transit…) and Links (roads)

– Scenario: for each season
  • People and affected area: demand in each node
  • Roads conditions for distributing relief aid (links capacities)
Model description: criteria

• Unmet demand
• Response time
• Cost
  • Strategic cost
  • Tactical and operational cost
Model description: criteria

• Unmet demand
• Response time
• Cost
  • Strategic cost
  • Tactical and operational cost
Model description: criteria

- Unmet demand
- Response time
- Cost
  - Strategic cost
  - Tactical and operational cost
Model description: criteria measures

**Unmet demand:**
- Stochastic (for each scenario and commodity)
- Expected value per season
- Chance constraints: limited probability

**Cost:**
- Deterministic cost (strategical) + Stochastic cost (response and prepositioning)
- Expected value of budget deviations

**Response time:** Hard constraints limiting origin of aid

MULTIOBJECTIVE OPTIMISATION: Pareto Frontier
Model description: scenarios

For each period, scenarios \( \Omega^t \subseteq \Omega \) \( (t \in T) \). For each \( \omega \in \Omega^t \):

- a weight or probability \( W^\omega \),
- demand of commodity \( o \) in the network node \( i \), \( D^i\omega_o \)
- capacity of network link \( a \), \( N^\omega_a \), and cost \( C^\omega_o,a \)

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• Scenarios generation
Scenarios generation: description

• Recurrent disasters: Historical data
• Disaster type data: consequences very dependent on the type of disaster
• Geographical data: disasters and their consequences very dependent on the location
• Scarce reliable information (Unlike what happens today in data science)
  – Especially developing countries: bad or few information registered
• Several data sources
Scenarios generation: procedure

For each type of disaster, based on historical cases

- **Phase 1- Global demand classes:** Scenarios for the total amount of people in need (affected, homeless)
- **Phase 2- Fuzzy classification:** allocation of original cases into the classes (scenarios)
- **Phase 3- Geographical scenarios:** For each class (scenario), clustering for spatial distribution of demand
- **Phase 4- Merging scenarios:** crossing different types of disasters
- **Phase 5- Scenarios reduction:** clustering of scenarios
Phase 1: Global demand classes

Scenarios Global demand (affected+homless)

- **Discrete distribution fitting moments of continuous distribution** estimated from n data $M_1, M_2, M_3... M_s$
- Number of scenarios predefined (Sturgess) (K)
- Extra conditions:
  - Worst case: at least worse than the worst historical case
  - Dispersion: minimum distance between scenarios (c)
  - Minimum probability: established on $1/n$
- Multivariate distribution for type of relief aid (affected/homeless...): **Regression**
Scenarios generation: Phase 1

Drought

Flood

Storm
Phase 2: Fuzzy classification

Fuzzy allocation of original cases into the classes (demand scenarios)

For each historical case:

- Distance of historical case $O_j$ to the scenario value $x_s$:
  difference of accumulated probabilities lognormal distribution

$$d(O_j, x_s) = \left| F(O_j) - F(x_s) \right|$$

$$F \approx LN \left( M_1 \{ \ln(O_1), ..., \ln(O_n) \} , M_2 \{ \ln(O_1), ..., \ln(O_n) \} \right)$$

(parameters of normal distribution associated)

- Threshold for maximum distance allowed $\tau$

$$d(O_j, x_s) = \left| F(O_j) - F(x_s) \right| < \tau$$
Scenarios generation: Phase 2
Scenarios generation: Phase 2
Scenarios generation: Phase 2
Scenarios generation: Phase 2
# Case study: Flood scenarios

| Data  | 300  | 500  | 3500 | 6925 | 17000 | 47837 | 50000 | 63946 | 70000 | 75000 | 100003 | 113535 | 171600 | 177645 | 20000 | 20000 | 288500 | 315986 | 400000 | 415000 | 440000 | 500000 | 50000 | 549326 | 4500000 |
|-------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|-------|-------|-------|-------|-------|-------|-------|------|-------|--------|

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**Ph1** and **Ph2.1**

Source: www.mat.ucm.es/humlog
# Flood scenarios

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**Ph2.2**

www.mat.ucm.es/humlog
# Case study: Storm scenarios

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Sources: www.mat.ucm.es/humlog
### Storm scenarios

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Phase 3- Geographical scenarios

Clustering of cases in each class and representing scenarios

3.1 Geographical scenarios with historical cases allocated

- Maximum number of geographical scenarios defined (G)
- Clustering of cases: G clusters with weighted cases
- A scenario representing each cluster

3.2 Complete scenarios with information on roads damages

- Other sources: Google Maps
- Expert knowledge to infer road quality from normal conditions (vulnerability)
- Update capacities based on damage on people (severity)
Scenarios generation: Phase 3
For each class (scenario): Clustering for spatial distribution of demand
Phase 4: Aggregation of consequences for several type of disasters

\[ |\Omega| = 1647 \]
Phase 5: Reduction of the number of scenarios

$|\Omega| = 91$ (umbral $\Phi = 0.8$)
• Case Study: Mozambique
Case study: Mozambique
Case study: Mozambique
Case study: Mozambique

Figure 4: Historical Cyclone Path, 1960 to 2002

Data from: INAM FEWS NET/MIND

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Case study: Mozambique

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Case study: Mozambique

- **Disasters:** Flood, Storm, Drought, Epidemic, Earthquake
- **Slow onset:** Drought, Epidemic (no roads damages)
- **Rapid onset:** Flood, Storm, Earthquake (no data)
- **Databases:** EMDAT, DESINVENTAR
- **Few information, high contradiction and not accurate information**
- **Big efforts to cross information from both databases**
Case study: Mozambique

- Data sources:
  - EMDAT
  - Desinventar
  - Google maps
  - Mozambican entities (meteorology, transport...)
  - Logistic cluster
  - NGOs, Red Cross...
Case study: data sources

- **EM-DAT** (from CRED, UCL): the most complete and reliable public database for disasters
  - Location (coordinates)
  - Type of disaster and magnitude of phenomenon
  - Killed
  - Injured
  - Homeless
  - Affected
  - Damage ($)

No geographical distribution, no infrastructure damage
Case study: data sources

- **DESINVENTAR**: collaborative database
  - Location: regions/district
  - Type of disaster and magnitude of phenomenon
  - Killed
  - Injured
  - Homeless
  - Affected
  - Crops and infrastructure (limited)

No reliable (no supervision on time, duplicated cases), many missing data, many descriptive data, limited countries

Crossing information of both databases

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Case study: Mozambique
Case study: Mozambique

Nodes: 128 districts
Arcs: 278
Case study: Mozambique

- **Capacity** of network link $a, N_{a,\omega}$
- **Unit transportation cost** through link $a, C^o_{a,\omega}$
Case study: Nampula
Case study: Nampula

- 21 nodes and 78 links.
- 35 scenarios (19 in June-July-August).
- 5 years with 4 seasons per year.
- 183,733 rows, 259,288 columns, and 105 binary variables.
- Average runtimes 3695s.
Pareto Frontier
Warehouse capacities in Pareto Frontier

![Diagram showing warehouse capacities over stages (years)]

- Installed capacity
- Unmet demand
- Budget deviation

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Store capacities distribution

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Conclusions

• A model developed to support decisions on:
  – when and where to build warehouses and capacities
  – how much relief aid to be prepositioned under uncertainty
  – Stochastic measures of consequences (Unmet demand, cost)

• **Input: Scenarios** of affected people

• A procedure for **scenarios generation** based on moments fitting, fuzzy allocation of cases and clustering for geographical scenarios

• **Input data: historical cases**

• **Case study in Mozambique:** Scarcity of accurate information
Cooperation of UCM-HUMLOG and GLC

- **UCM-HUMLOG can provide:**
  - Models (tools) for managing warehouses, budget estimation, prepositioning, transportation...
  - A website to provide information especially to Academia (for free), diminishing requests to GLC and partners
  - Secondments, consulting, education

- **GLC can provide to UCM-HUMLOG:**
  - Cooperation for designing tools defined by end users requirements
  - Agreement in order to get funds to develop the tools (supporting the group getting funds is easier)

Others?

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