Multiobjective stochastic optimisation for long and short-term planning of prepositioning in humanitarian logistics

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UCM-HUMLOG: Decision aid models for logistics and disaster management (Humanitarian Logistics)

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Disaster Risk Reduction

- DRR: concept and practice of risk reduction through sistematic efforst to analyse and reduce the causal factors of disasters
  - Reduction of the exposure to hazards
  - Reduction of the population vulnerability
  - Rational management of the land and the environment
  - *Improvement of preparedness and response to adverse events*

- **DISASTER:** Disruption of the normal functioning of a system or community, in a specific geographical area and limited time, which causes a strong impact on people, structures and environment, and goes beyond local capacity of response.

Levels and entities (decision makers)

1

Local Level (L1)

Civil organizations and population

Local agents (police, firefighters…): Local civil protection

2

National/regional Level (L2-L3)

National civil protection, Army, Other governmental agencies, Red Cross and Humanitarian NGOs

3

International Level (L4-L5)

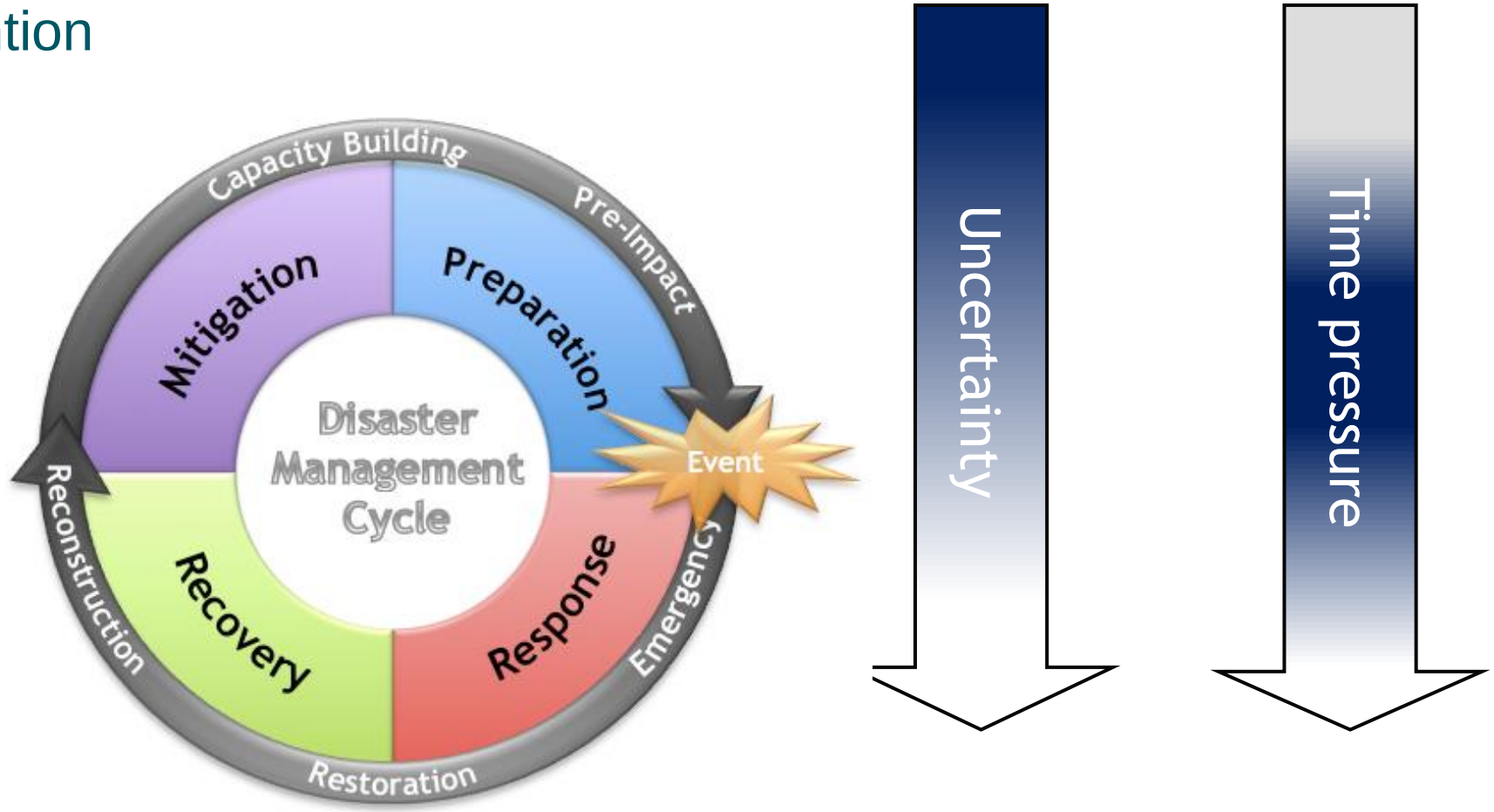
Foreign governments (ECHO, USAID)

IHO.: Red Cross, MSF,ACF, Oxfam, Care, World Vision, Save the Children

UN: OCHA, Agencies (UNICEF, WFP, UNDP, UNHCR). IASC (Inter-Agency Standing Committee)

The disaster cycle

- Mitigation/Prevention
- Preparedness
- Response
- Recovery
- Evaluation



Humanitarian logistics

- Process of planning, implementing and controlling the efficient, cost-effective flow of and storage of goods and materials as well as related information, from the point of origin to the point of consumption, for the purpose of alleviating the suffering of vulnerable people

Activity areas

- Assessment/ Planning
- Procurement
- Warehousing
- Transport

- Reports
- Operations support

Humanitarian logistics

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

Contents

Preparedness: strategic and tactical decisions

- Disasters can be **seasonal** (rains, cyclones, droughts), or non seasonal (earthquakes,…)
- Many countries suffer **recurrent natural disasters**
- Disasters can be slow onset or **sudden onset**
- Authorities must **provide relief aid** to affected people under a **very high time pressure: prepositioning**

- Big amounts of **relief aid must be moved**
- Logistics is critical to provide relief at *right time, right place, right amount, right quality, right cost, right source* (**the six "rights"**)
- **First responders:** population, civil protection, governments, NGO on the country
- **Local capacities** critical to response (72 hours). International support will arrive with **delay**.

Preparedness model: local entities

- **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 humanitarian aid to be **acquired in emergency**?
  - How much humanitarian aid to be **acquired to restore stock levels**?

Preparedness model: elements

Model for strategical 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…)
  - 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 measures

Unmet demand:

- Stochastic (for each scenario and commodity)
- Expected value per season

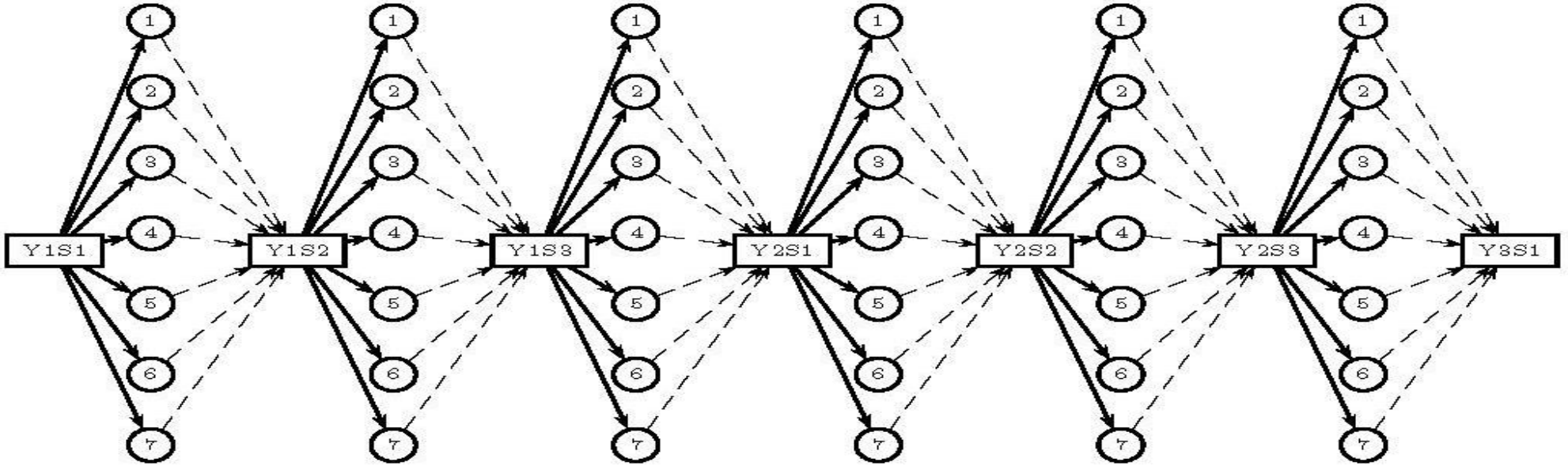
Cost:

- 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^{ω},
- **demand** of commodity o in the network node i, $D^{i\omega}{}_{o}$
- **capacity** of network link a, $N^{\omega}{}_{a}$, and cost $C^{\omega}{}_{o,a}$

Preparedness model: variables

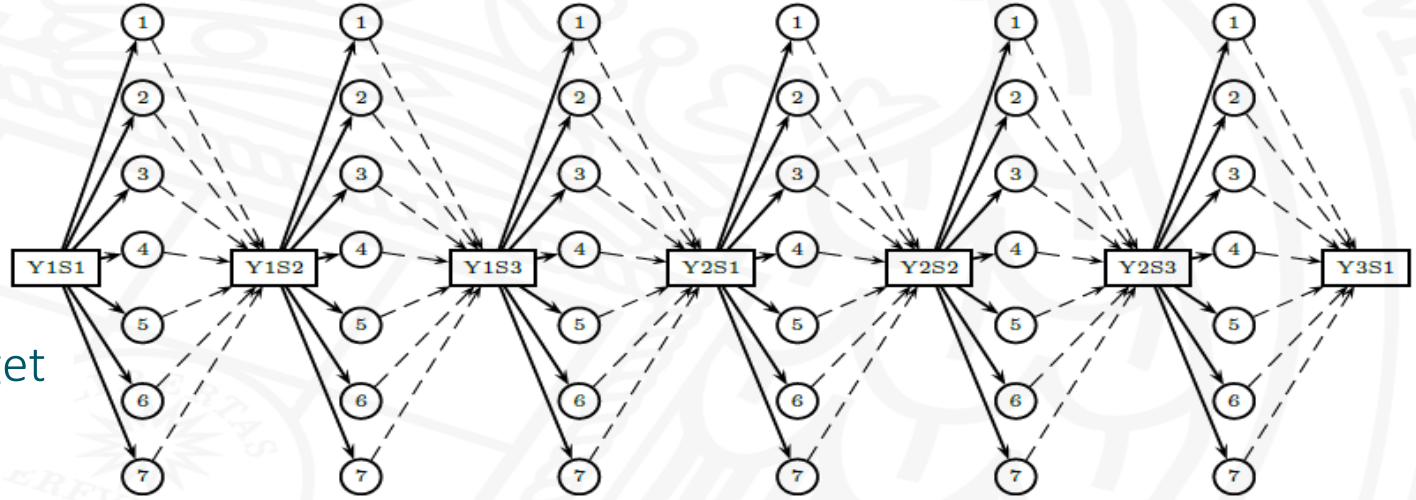
α_i^e warehouses location

f_i^e warehouses capacities

β_F^e facilities budget

β_T^t procurement and distribution budget

$\hat{s}_{oi}^t$ prepositioning



$$\gamma_o s_{oi}^{\omega} + r_{oi}^{\omega} - \tilde{r}_{oi}^{\omega} = \hat{s}_{oi}^{t+1}$$

$$\hat{s}_{oi}^t + x_{oi}^{\omega} + \sum_{a \in \Gamma_i^{-\omega}} y_{oa}^{\omega} =$$

$$= D_{oi}^{\omega} - v_{oi}^{\omega} + \sum_{a \in \Gamma_i^{+\omega}} y_{oa}^{\omega} + s_{oi}^{\omega} \quad \forall o \in \mathcal{O},\ i \in \mathcal{I}, \omega \in \Omega^t, t \in \mathcal{T}$$

Preparedness model: Budget allocation

$$\overline{C}^e \geq \beta_F^e + \sum_{t \in \mathcal{T}^e} \beta_T^t \quad \forall e \in \mathcal{E}$$

$$\sum_{i \in \mathcal{I}} B_i^e \left(\alpha_i^e - \alpha_i^{e-1}\right) + F_i^e \left(f_i^e - f_i^{e-1}\right) + \sum_{i \in \mathcal{I}} \tau_i \left(B_i^e \alpha_i^e + F_i^e f_i^e\right) = \beta_F^e \quad \forall e \in \mathcal{E}$$

$$\sum_{o \in \mathcal{O}} \sum_{i \in \mathcal{I}} \left(Q_{oi}^t \left(r_{oi}^\omega - \tilde{r}_{oi}^\omega\right) + C_{oi}^t x_{oi}^\omega\right) + \sum_{o \in \mathcal{O}} \sum_{a \in \mathcal{A}^\omega} G_o^L C_{oa}^\omega y_{oa}^\omega \leq \beta_T^t + v_T^\omega \quad \forall \omega \in \Omega^t, t \in \mathcal{T}$$

Preparedness model: multiobjective programming-weighting method

$$\min \quad \frac{\lambda}{Z_C - Z^C} \cdot \left(\sum_{t \in \mathcal{T}} \frac{1}{(1+\rho)^t} \sum_{\omega \in \Omega^t} W_\omega v_T^\omega - Z_C \right) +$$

$$\frac{1-\lambda}{Z_D - Z^D} \cdot \left(\sum_{o \in \mathcal{O}} M_o \sum_{\substack{t \in \mathcal{T}, \\ \omega \in \Omega^t}} \sum_{i \in \mathcal{I}} W_\omega v_{oi}^\omega - Z_D \right)$$

Preparedness model: scenarios generation

Scenario features:

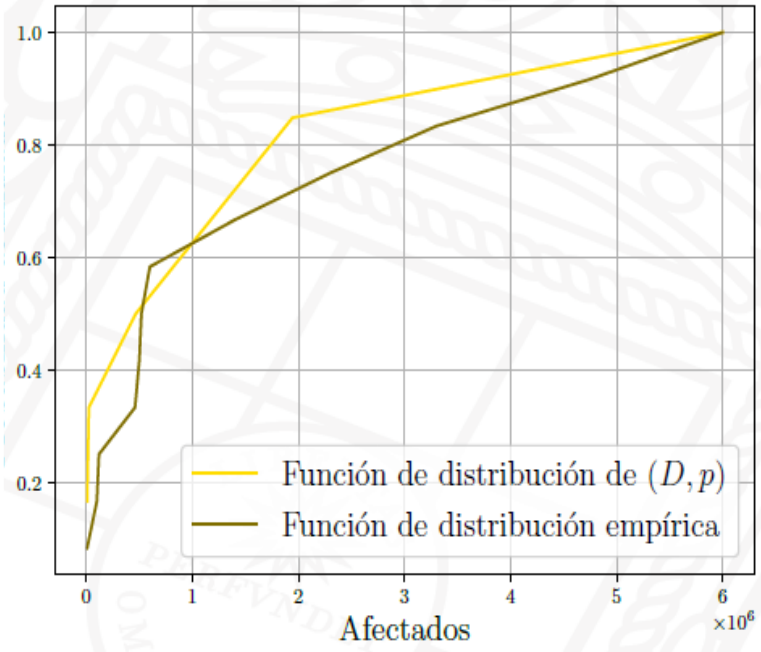
- a weight or **probability**,
- **demand** of commodity o in the network node i
- **capacity** of network link a and transport cost of commodity o through link a

Characteristics:

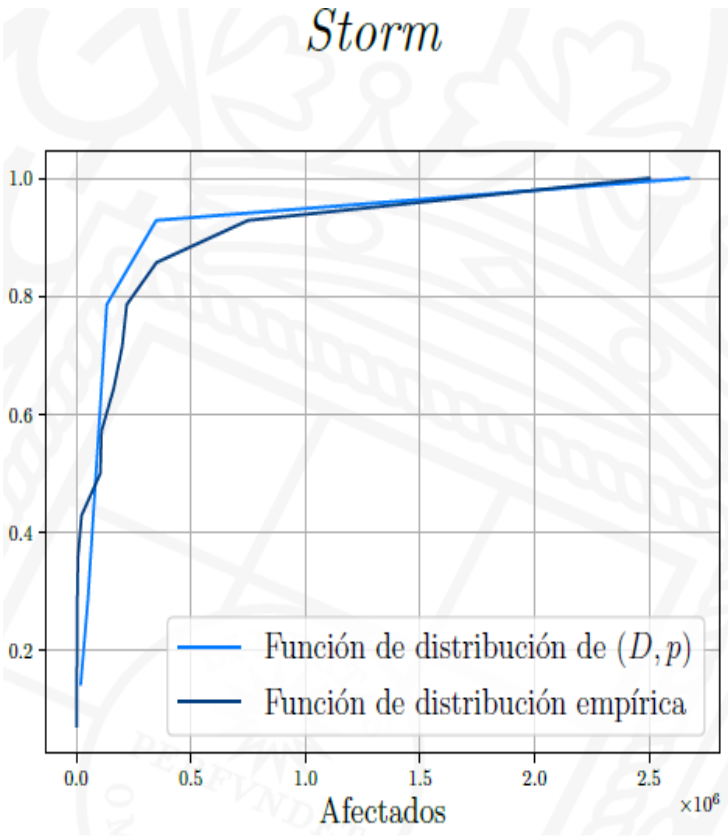
- Recurrent disasters: Historical data
- Disaster type data: consequences very dependent on the type of disaster
- Geographical data: disasters and their consequences very dependent on the location
- Scarce reliable information (Unlike what happens today in data science)
  - Especially developing countries: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

Scenarios generation: **Phase 1- Global demand classes**

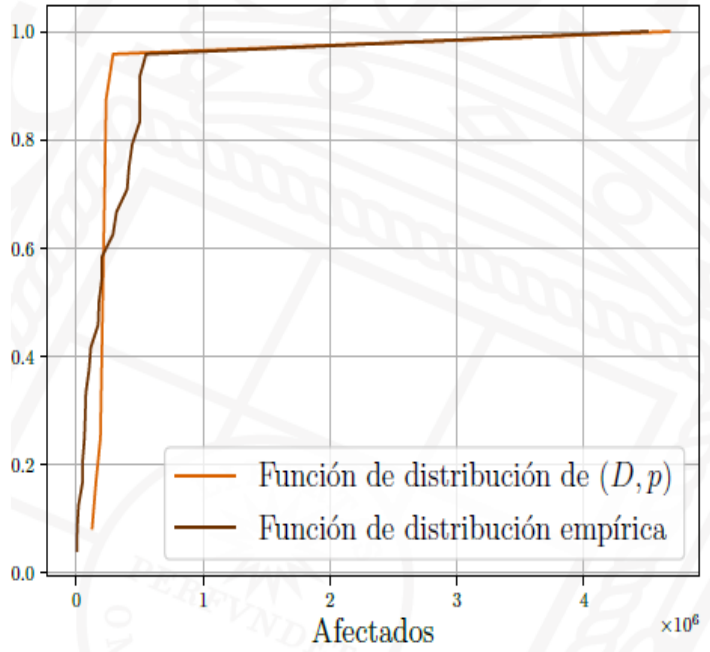
Drought



Storm



Flood



Flood scenarios

Data
300
500
3500
6925
17000
47837
50000
63946
70000
75000
100003
113535
171600
177645
200000
200000
288500
315986
400000
415000
440000
500000
500000
500000
549326
4500000

Ph1

s1	5281,8
s2	17949,6
s3	61000,1
s4	207303,6
s5	704503,2
s6	4604972,2

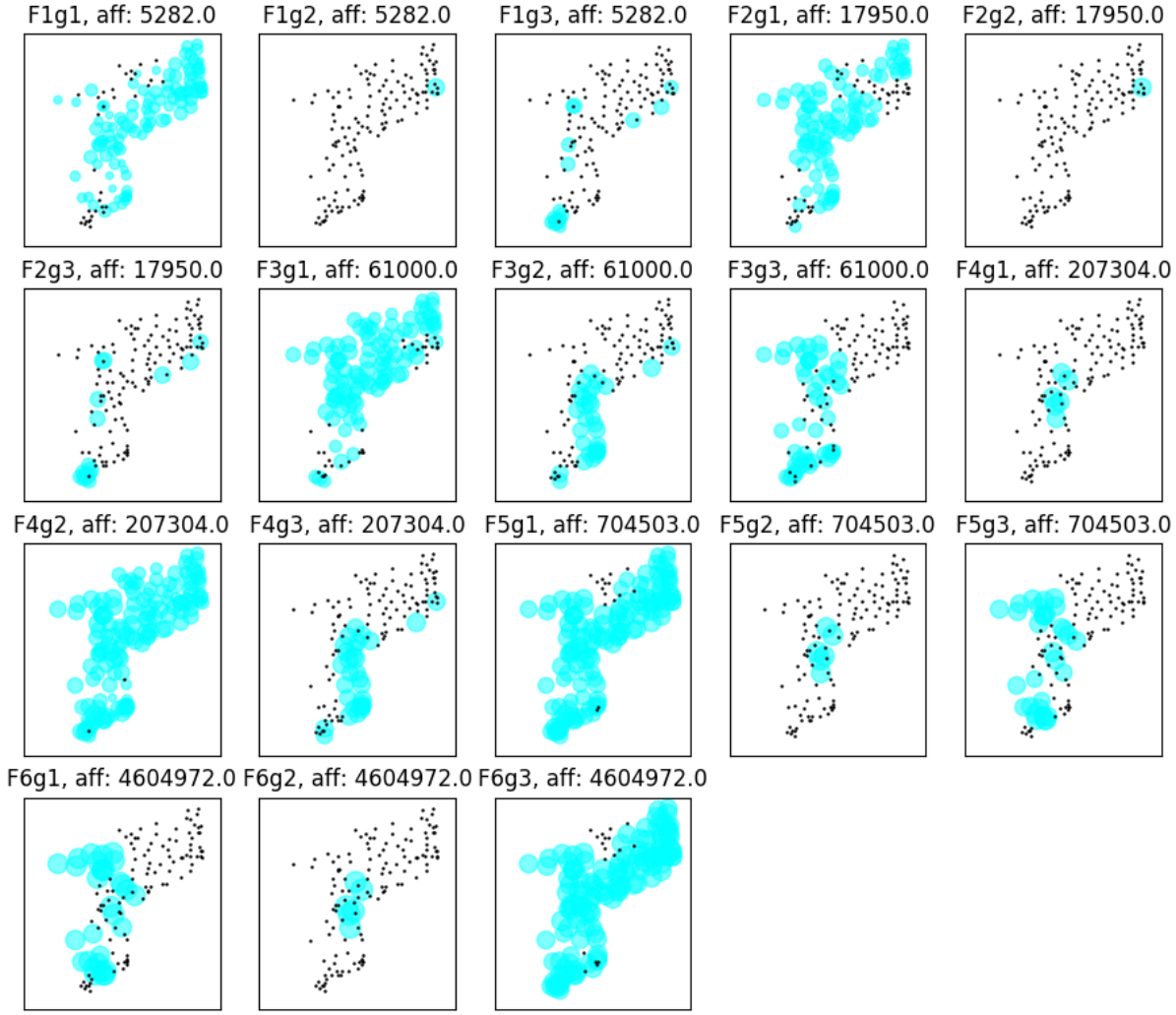
Ph2

s1 - 5282	s2 - 17950	s3 - 61000	s4 - 207304	s5 - 704503	s6 - 4604972
0,090977	0,222277	0,419718	0,638818	0,818243	0,958249
0,086851	0,218150	0,415592	0,634691	0,814117	0,954123
0,028083	0,159383	0,356825	0,575924	0,755350	0,895355
0,022696	0,108603	0,306045	0,525144	0,704570	0,844576
0,123896	0,007404	0,204845	0,423945	0,603370	0,743376
0,285821	0,154521	0,042920	0,262020	0,441445	0,581451
0,293538	0,162238	0,035203	0,254303	0,433728	0,573734
0,337191	0,205892	0,008450	0,210649	0,390075	0,530080
0,353482	0,222182	0,024741	0,194359	0,373784	0,513790
0,365967	0,234667	0,037226	0,181874	0,361299	0,501305
0,418301	0,287002	0,089560	0,129539	0,308965	0,448970
0,441365	0,310065	0,112624	0,106476	0,285902	0,425907
0,515186	0,383887	0,186445	0,032654	0,212080	0,352086
0,521234	0,389934	0,192493	0,026607	0,206032	0,346038
0,541716	0,410417	0,212975	0,006124	0,185550	0,325556
0,541716	0,410417	0,212975	0,006124	0,185550	0,325556
0,602375	0,471076	0,273634	0,054535	0,124891	0,264896
0,616709	0,485409	0,287968	0,068868	0,110557	0,250563
0,652272	0,520973	0,323531	0,104432	0,074994	0,214999
0,657609	0,526309	0,328868	0,109768	0,069657	0,209663
0,665962	0,534663	0,337221	0,118122	0,061304	0,201309
0,683668	0,552368	0,354926	0,135827	0,043599	0,183604
0,683668	0,552368	0,354926	0,135827	0,043599	0,183604
0,683668	0,552368	0,354926	0,135827	0,043599	0,183604
0,696203	0,564904	0,367462	0,148363	0,031063	0,171068
0,866406	0,735107	0,537665	0,318566	0,139140	0,000865

Flood scenarios

Data
300
500
3500
6925
17000
47837
50000
63946
70000
75000
100003
113535
171600
177645
200000
200000
288500
315986
400000
415000
440000
500000
500000
500000
549326
4500000

Ph3



Storm scenarios

Data
51
304
1100
1700
4000
4017
7103
23010
105000
109958
162770
200000
220013
350000
750102
2502000

Ph1 →

s1	51
s2	461
s3	4172
s4	37729
s5	341223
s6	2627952

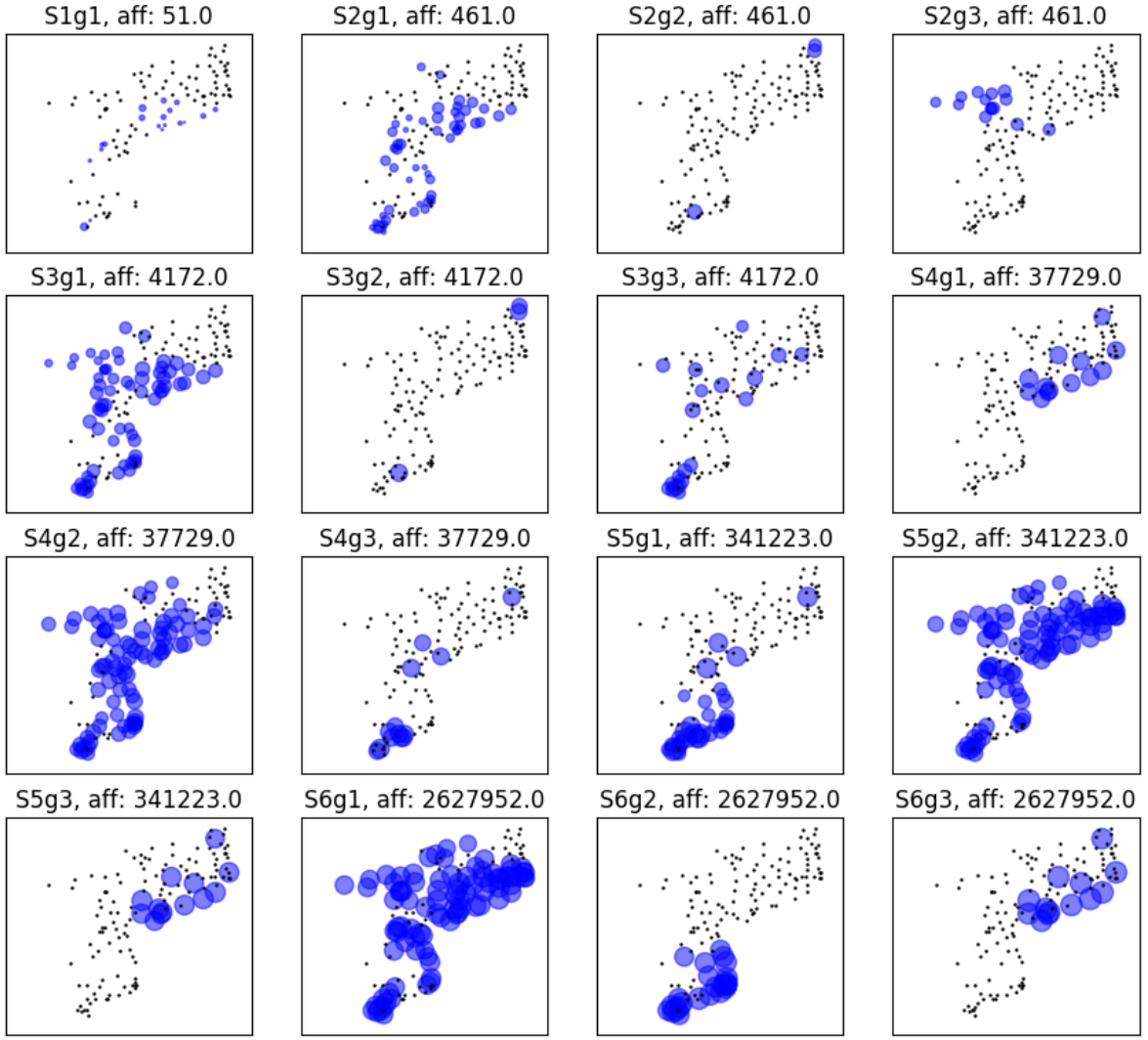
Ph2 →

s1 - 51	s2 - 461	s3 - 4172	s4 - 37729	s5 - 341223	s6 - 2627952
0	0,078347857	0,267597586	0,544686362	0,790991051	0,917898389
0,056209402	0,022138455	0,211388184	0,48847696	0,734781649	0,861688987
0,138387993	0,060040136	0,129209593	0,40629837	0,652603059	0,779510396
0,175768058	0,097420202	0,091829527	0,368918304	0,615222993	0,74213033
0,262885332	0,184537475	0,004712254	0,28180103	0,528105719	0,655013057
0,263358363	0,185010507	0,004239222	0,281327999	0,527632688	0,654540025
0,330033588	0,251685732	0,062436003	0,214652774	0,460957463	0,5878648
0,480318172	0,401970315	0,212720586	0,064368191	0,31067288	0,437580217
0,670627478	0,592279621	0,403029892	0,125941116	0,120363573	0,247270911
0,675917808	0,597569951	0,408320222	0,131231445	0,115073244	0,241980581
0,719131848	0,640783992	0,451534263	0,174445486	0,071859203	0,198766541
0,74046318	0,662115323	0,472865594	0,195776818	0,050527871	0,177435209
0,750000782	0,671652926	0,482403197	0,20531442	0,040990269	0,167897606
0,793213755	0,714865898	0,525616169	0,248527393	0,002222704	0,124684634
0,852145532	0,773797675	0,584547946	0,307459169	0,06115448	0,065752857
0,915977276	0,837629419	0,64837969	0,371290914	0,124986225	0,001921113

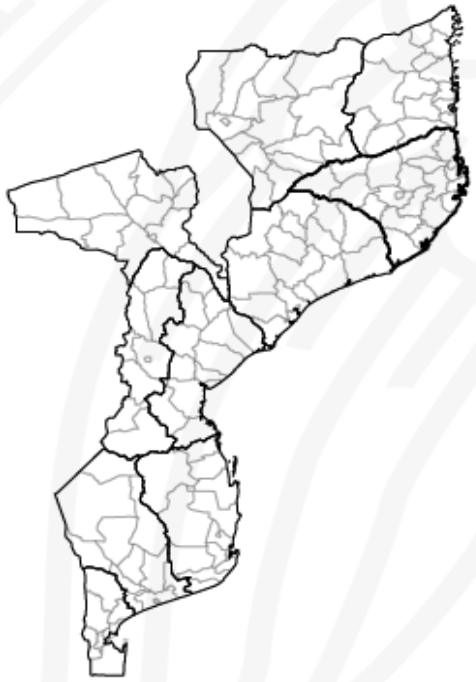
Storm scenarios

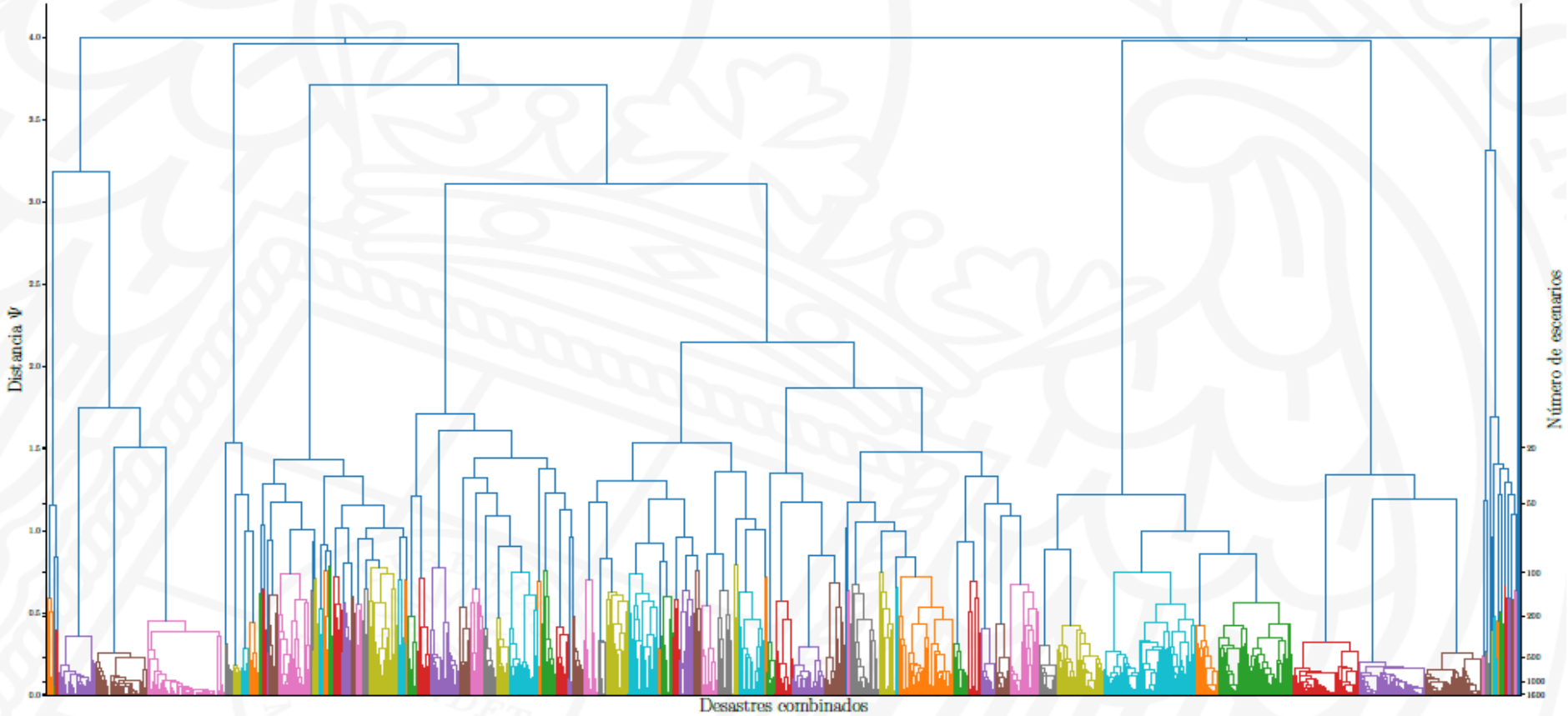
Data
51
304
1100
1700
4000
4017
7103
23010
105000
109958
162770
200000
220013
350000
750102
2502000

Ph3 →



Scenarios: merge and reduction





$|\Omega| = 91$ (umbral $\Phi = 0{,}8$)

Contents

Case study: Mozambique

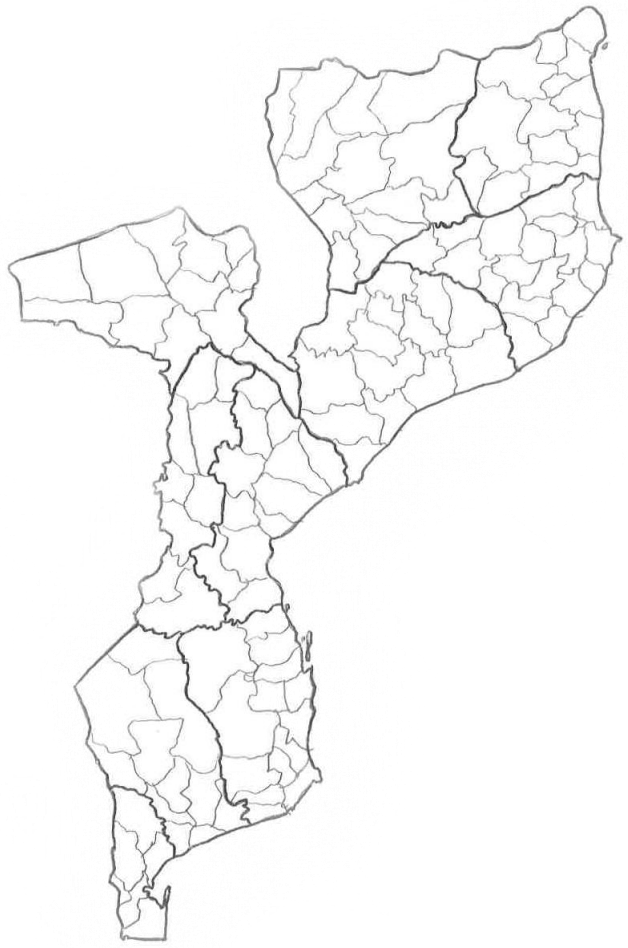
- Data sources:
  - EMDAT
  - Desinventar
  - Google maps
  - Mozambican entities (meteorology, transport…)
  - Logistic cluster
  - NGOs, Red Cross…

Case study: Mozambique

- Disasters: **Flood, Storm, Drought,** Epidemic, Earthquake
- Slow onset(no roads damages): Drought, Epidemic
- 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



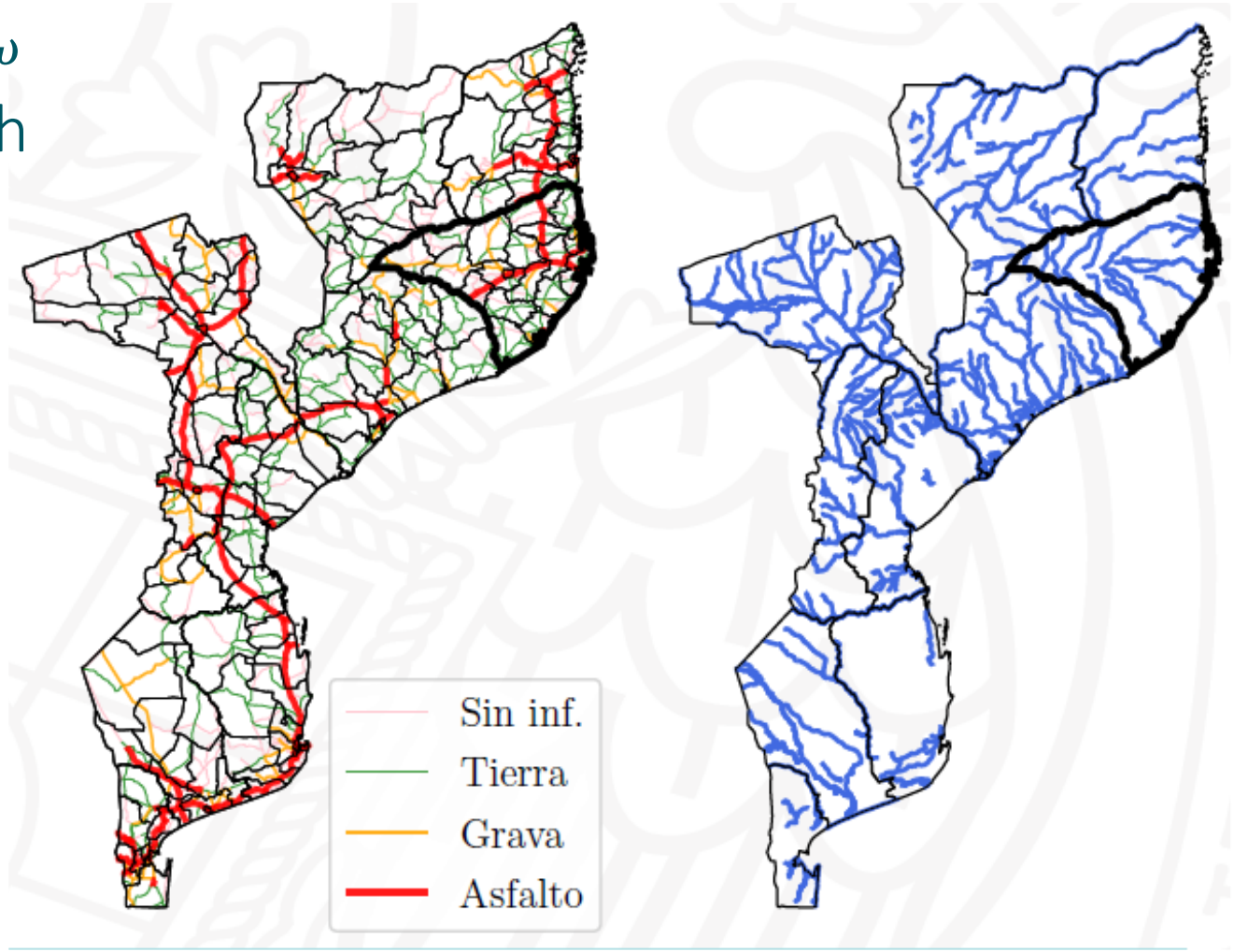
Case study: Mozambique

Nodes: 128 districts

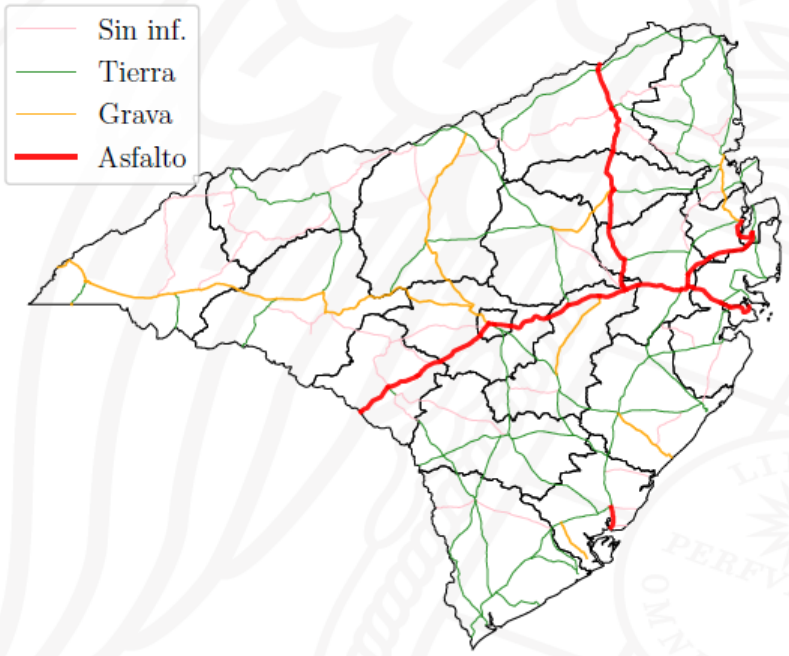
Links: 278

Case study: Mozambique

- **Capacity** of network link a, $N_{a,\omega}$
- Unit **transportation cost** through link a, $C^{o}_{a,\omega}$



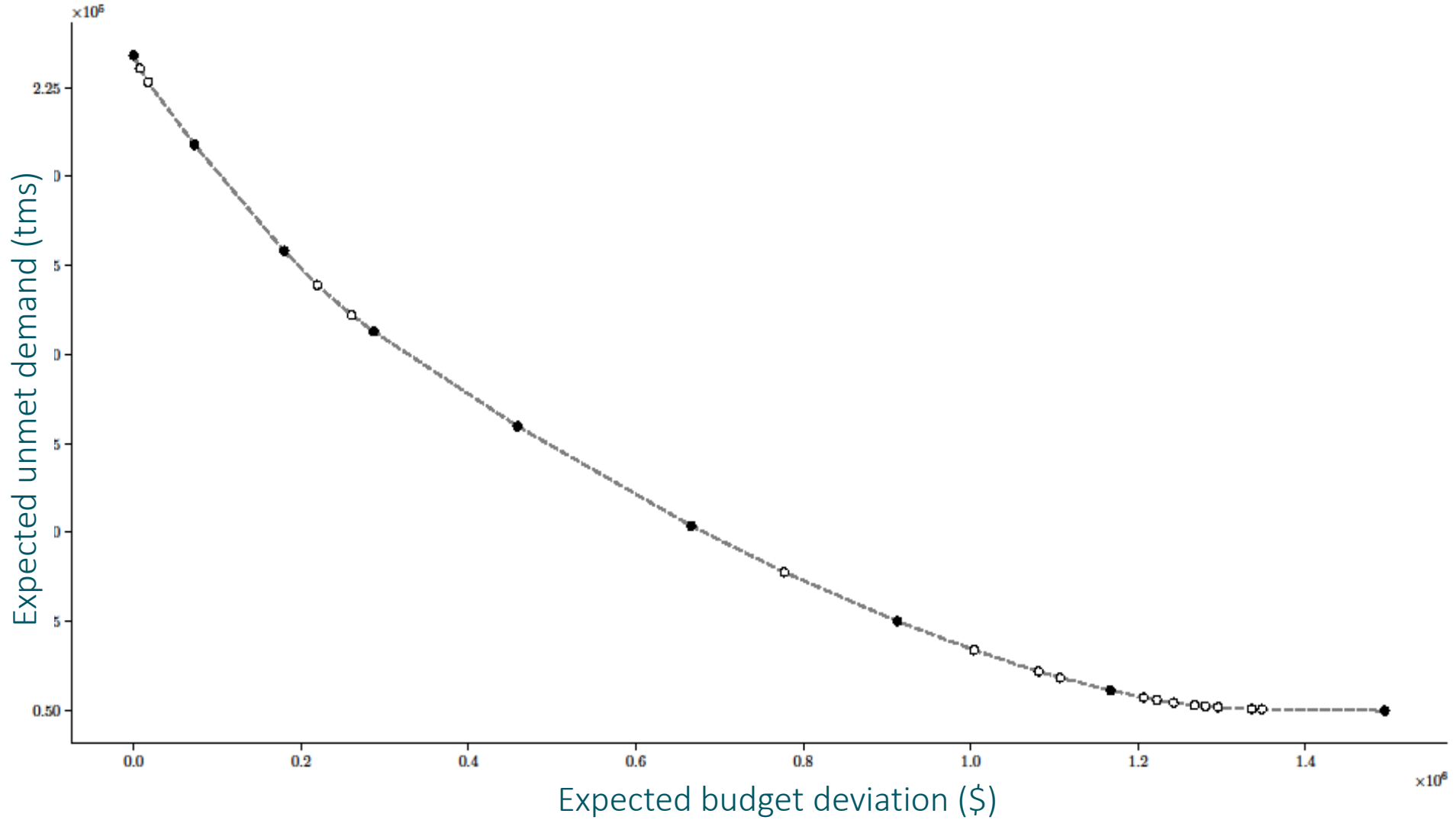
Case study: Nampula



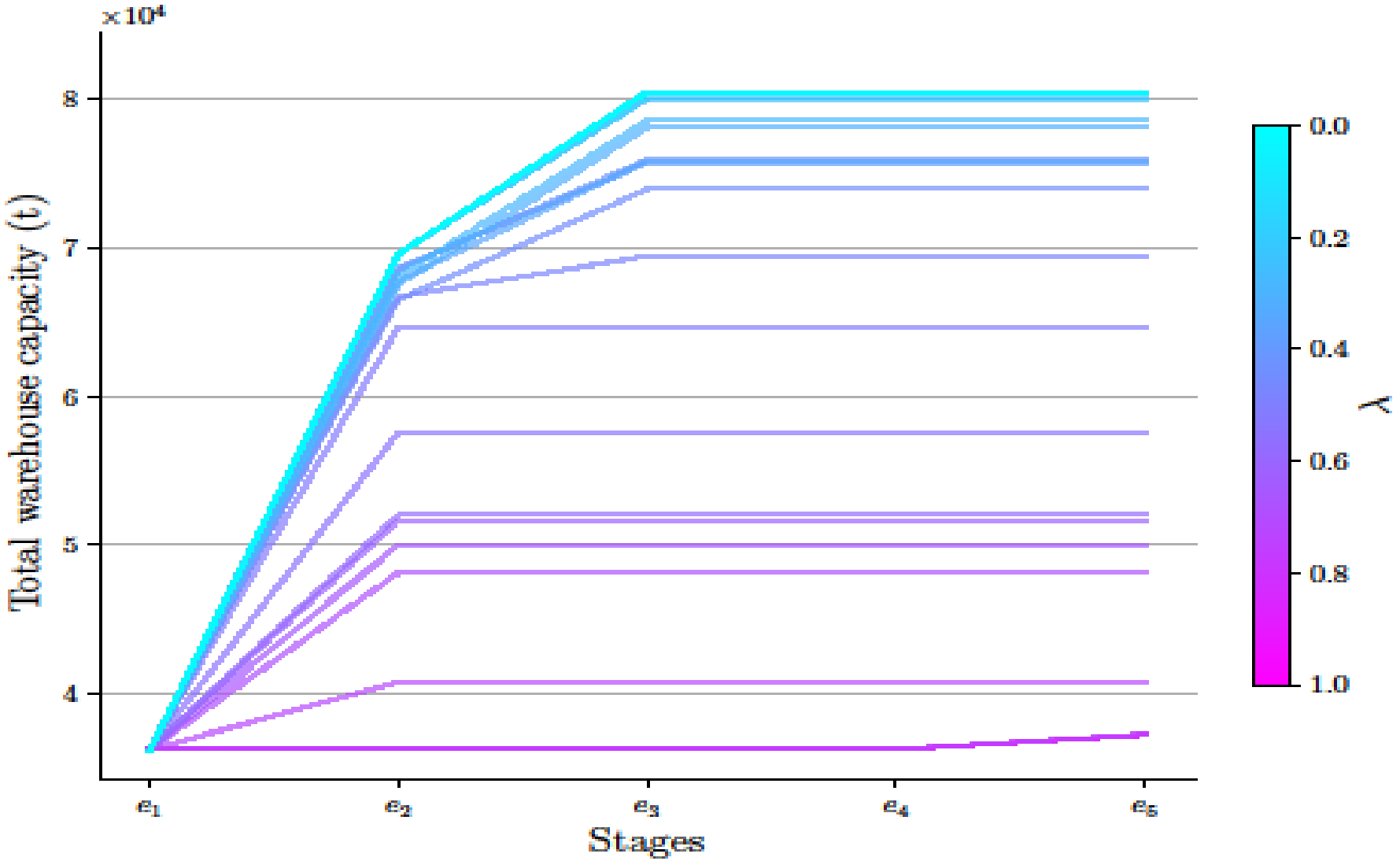
Case study: Nampula

- 21 nodes y 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.

Pareto Frontier



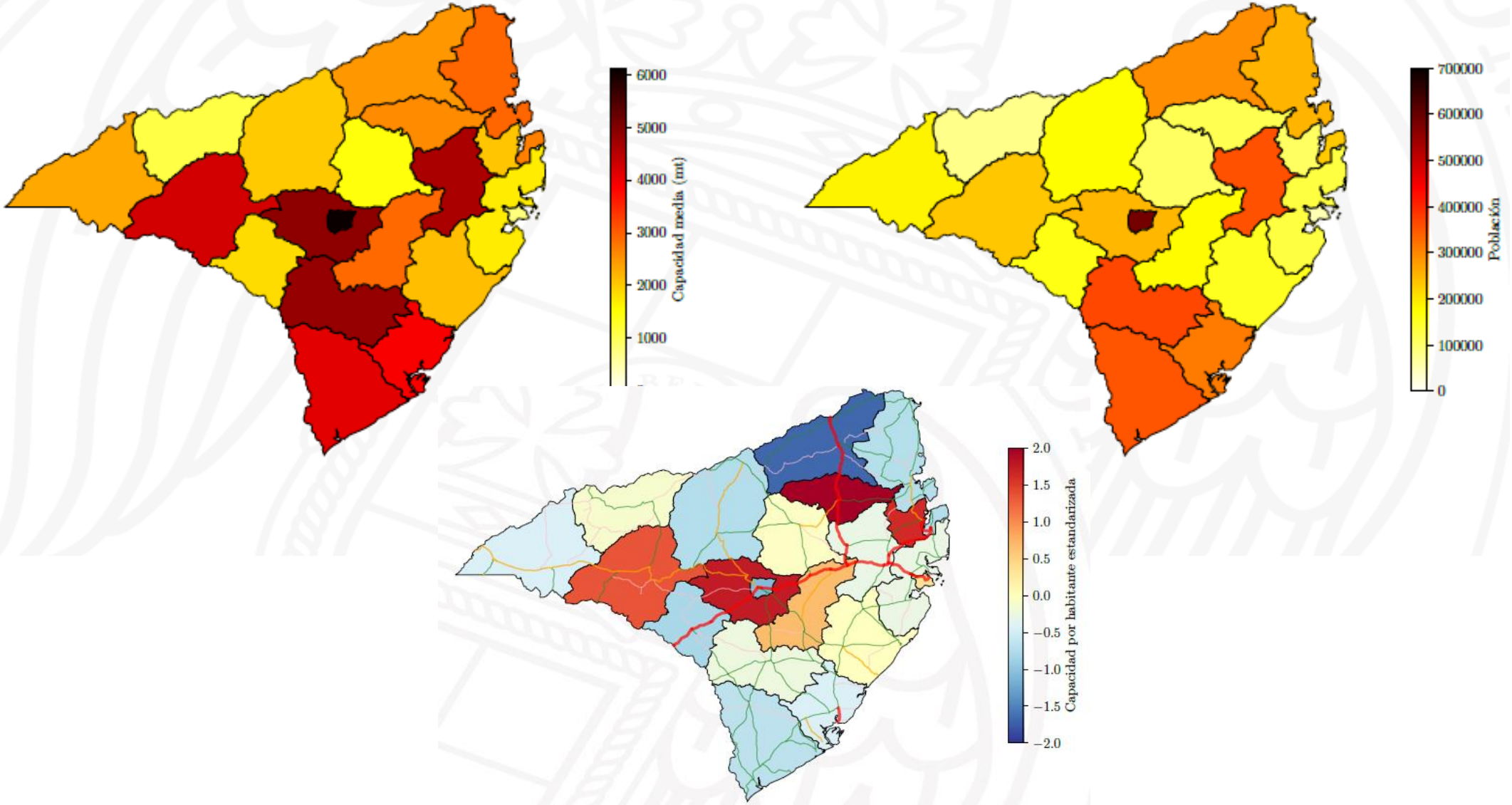
Warehouse capacities in Pareto Frontier



Unmet demand

Budget deviation

Warehouse capacities installed



Contents

Exploring alternatives

- Objective:
  - Solving the model for full Mozambique
  - Other measures (CVaR…)
  - Working with INGD of Mozambique (research project, students…)
- Difficulties: high running times
- Alternatives for modelling and methodologies:
  - Breaking symmetries: Different building costs (the further away from the airport/port the more expensive it is)
  - Weighting method vs e-constraints: e-constraints looks better
  - Impulse variables vs pulse variables
- Alternatives for solving:
  - Benders decomposition
  - Heuristics

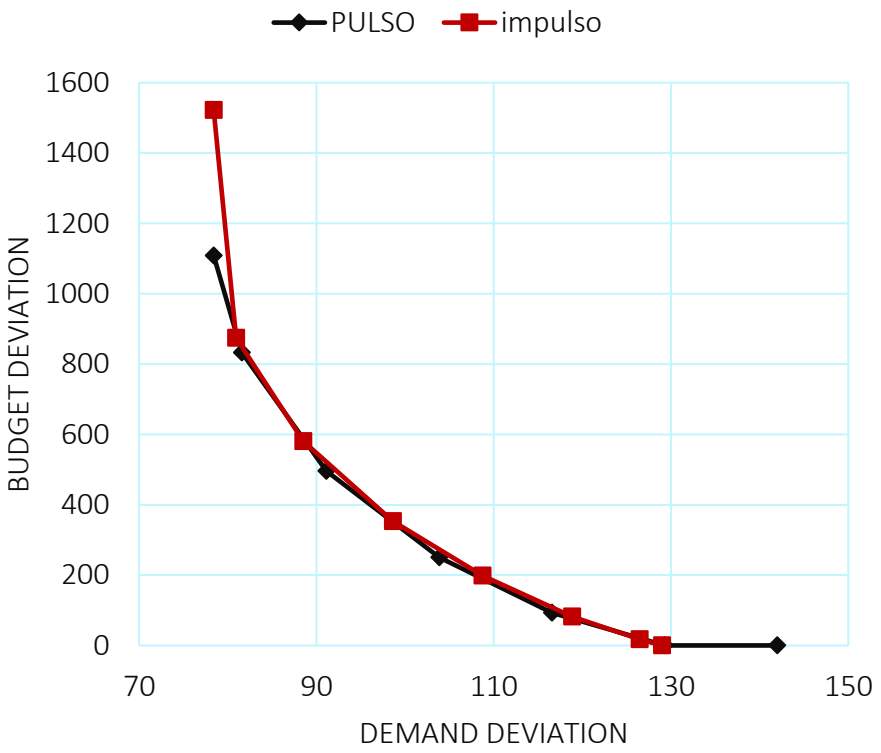
Experiments

- Experiment 1: comparing impulse-pulse variables with runtime limit 20 hours
  - Minimising cost, e-constraint demand
  - Findings:
    - Payoff matrix pulse-payoff matrix impulse

78,425	1108,293
142,001	0

78,425	1522
128,979	0

    - Similar Pareto Frontier
    - Incumbent solutions: no significant differences after 2h
  - Conclusion:
    - Comparison limiting runtime 2 hour
    - Affect values (initial solution in loops different)
    - Breaking symmetries

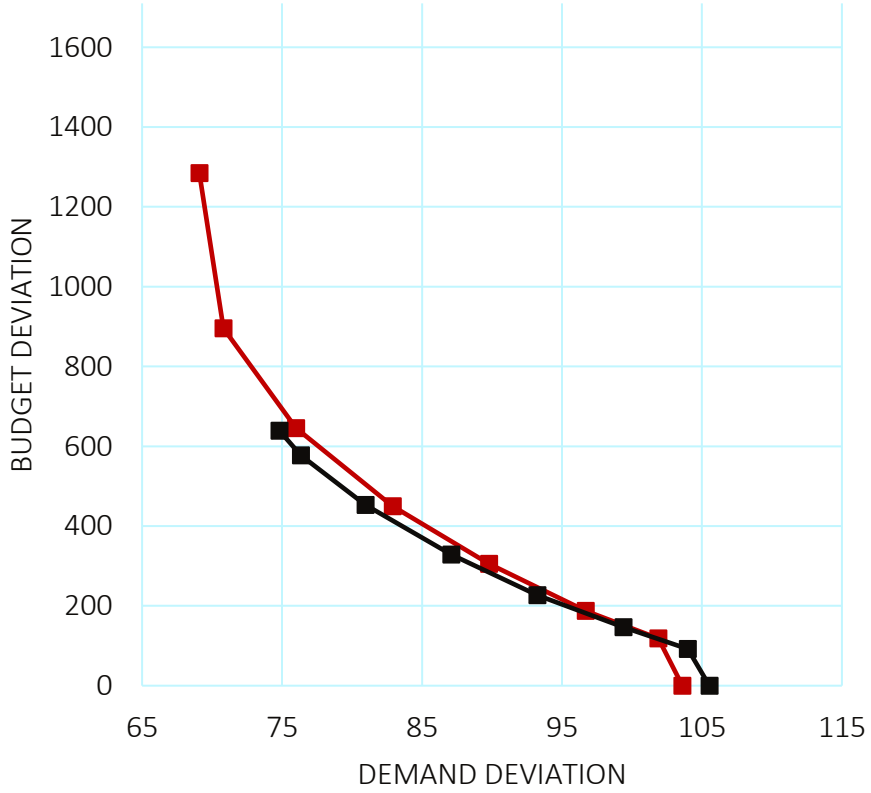


Experiments

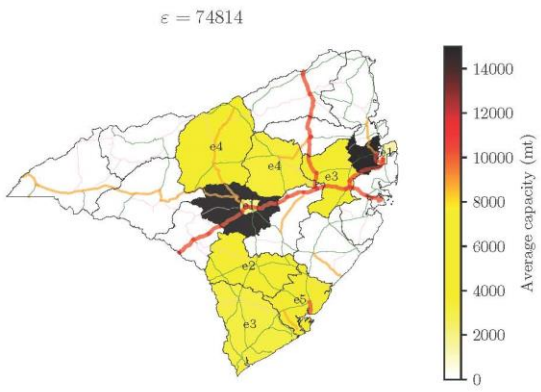
- Experiment 2: comparing impulse-pulse variables with runtime limit 1 hour
  - Building cost changing with distance to airport/port
  - Minimising cost, e-constraint demand
  - Findings:
    - Payoff matrix pulse-payoff matrix impulse

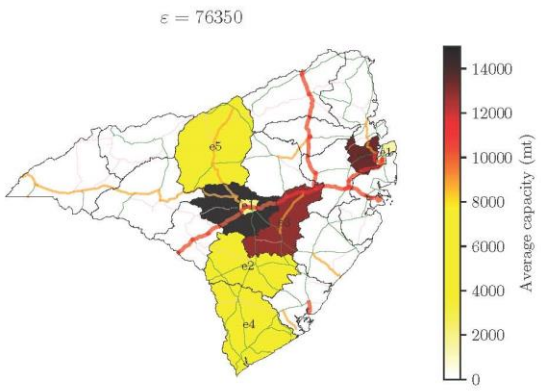
74,81	639,11	69,09	1284,61
105,53	0	103,6	0

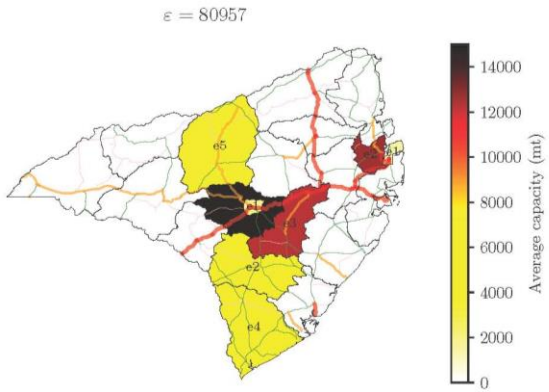
    - Including lower bound for demand can be worse (639,11)
    - Difficult to change binary variables in loop for Pareto Frontier

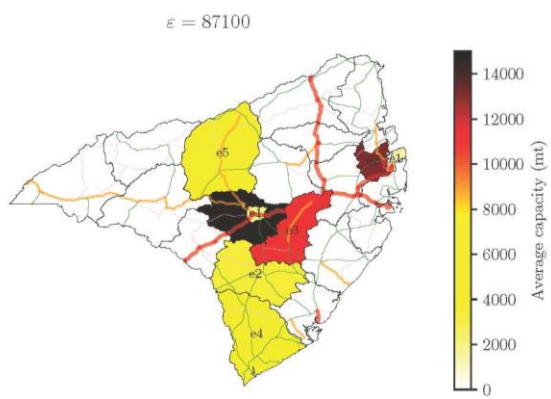


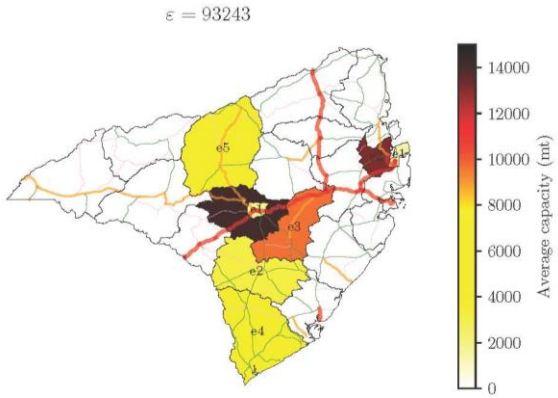
Solution with pulse variables and asymmetric costs

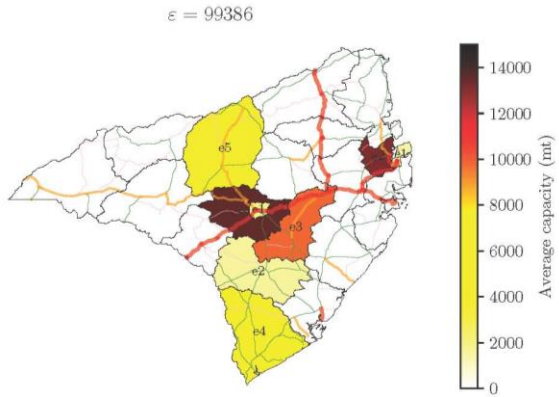


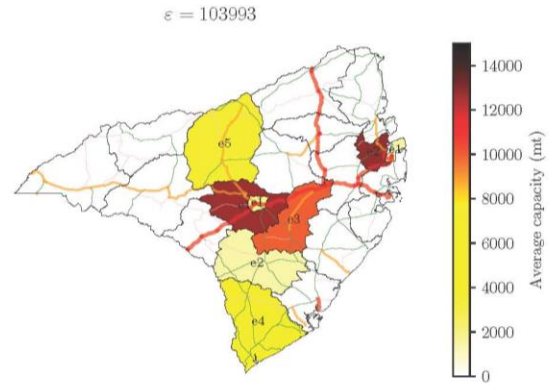


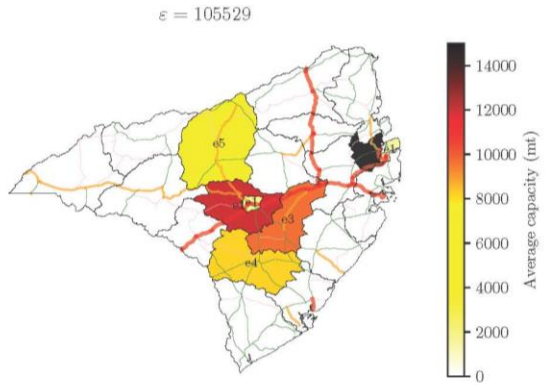












Contents

Conclusions

- Humanitarian logistics is key to provide relief aid to people in need
- A multicriteria model has been developed for:
  - Strategic decisions: relief aid warehouses location and sizing
  - Tactical decisions: relief aid prepositioning and budget reserved

  considering:
  - Operational decisions on different scenarios
  - Expected unmet demand (72h)
  - Expected budget deviation (72h)
- Runtimes are too high
- Work made reducing times: pulse formulation, e-constraints, changes in costs
- Work in progress: Benders decomposition
- Future objective: solving the full case Mozambique, validate it with the INGD