



# Operations Research for the Common Good



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*UCM-HUMLOG Group: Decision models in logistics  
and disaster management (Humanitarian Logistics)*

*Universidad Complutense de Madrid*

# Contents



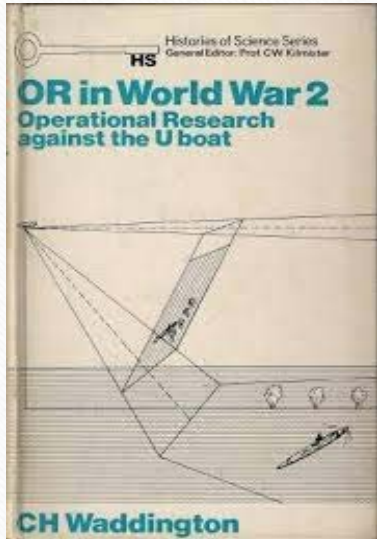
**1** Operations Research for the Common Good

**2** Disaster management. Humanitarian Logistics

**3** Some OR Models in Humanitarian Logistics

**4** Case Studies

**5** Conclusions



## From military logistics to industrial optimization



## From supply chains to financial systems...



- Improve efficiency
- Reduce costs
- Enhance performance

# In a World facing

Climate  
change

Growing  
inequality

Fragile  
health  
systems

Humanitarian  
crises

Resource  
scarcity

WARS...



To decide better  
when life matters



## Healthcare Systems



- ICU and operating room capacity planning
- Organ allocation policies
- Vaccine distribution under uncertainty
- Ambulance location and dispatch models

## Humanitarian & Disaster Response



- Prepositioning of relief supplies
- Last-mile distribution under infrastructure damage
- Evacuation planning for vulnerable populations

## Climate & Energy Transition



- Renewable energy integration in power grids
- Infrastructure investment
- Carbon-aware transportation network design
- Solar-Home-Systems maintenance plans.

## Environmental & Natural Resource Management

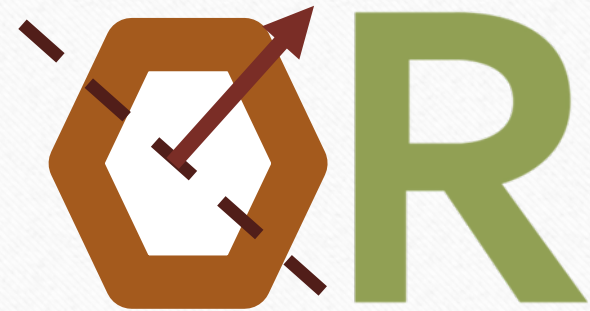


- Water reservoir management
- Wildfire suppression resource allocation
- Waste collection network design

# Disaster Disaster Disaster



To decide better  
when life matters



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# Hazards, Disasters and Emergencies

- ❑ **HAZARD:** agent with the potential to cause harm to a vulnerable target.
- ❑ **Hazard vs. risk:** In terms of risk assessment, hazard: agent that can cause harm or damage to humans, property, or the environment. Risk: probability that exposure to a hazard will lead to a negative consequence. (a hazard poses no risk if there is no exposure).
- ❑ **DISASTER:** Disruption of the normal functioning of a system or community, in a specific geographical area, which causes a strong impact on people, structures and environment, and goes beyond local capacity of response.

# Hazards and disasters: classification

By natural causes

Sudden occurrence

Storm

Heat Wave

Freeze

Earthquake

Volcanic Eruption

Fire

Progressive occurrence

Landslide

Drought

Flood

Epidemic

Pest

By human causes

Sudden occurrence

Fire

Explosion

Collision

Shipwreck

Structural Collapse

Environmental Pollution

Progressive occurrence

War

Economic Crisis

Environmental Pollution

Vulnerability  
Insufficient capacity of response

**DISASTER**

## Number of recorded natural disaster events, 1900 to 2022

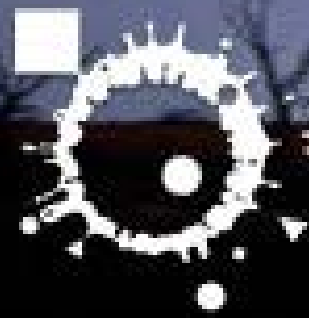
Our World  
in Data

The number of global reported natural disaster events in any given year. This includes those from drought, floods, extreme weather, extreme temperature, landslides, dry mass movements, wildfires, volcanic activity and earthquakes.



Source: EM-DAT, CRED / Université catholique de Louvain, Brussels (Belgium)

OurWorldInData.org/natural-disasters • CC BY



# EM-DAT

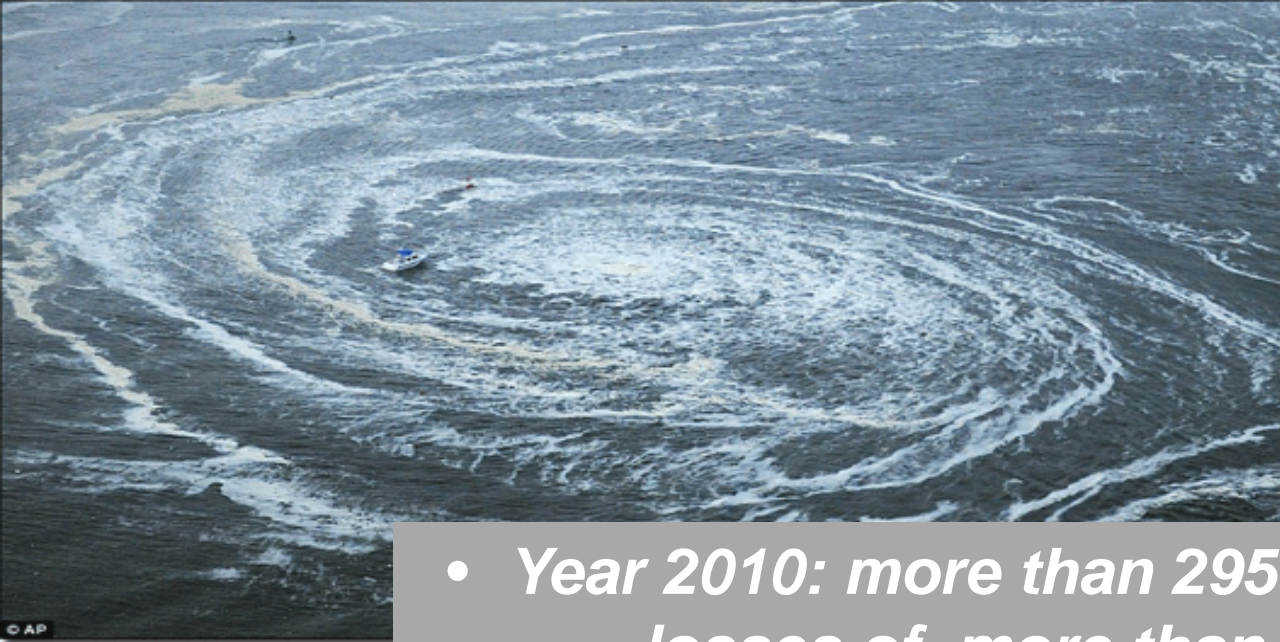
## The International Disaster Database

Centre for Research on the Epidemiology of Disasters - CRED

### What are the EM-DAT disaster criteria?

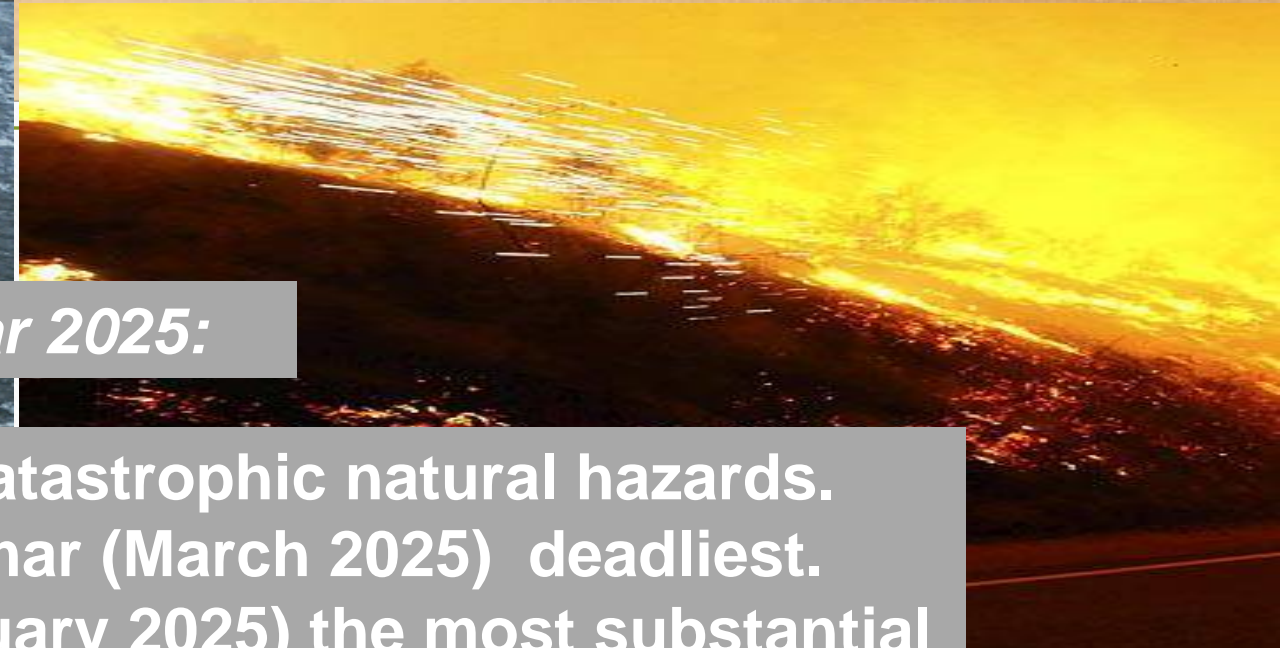
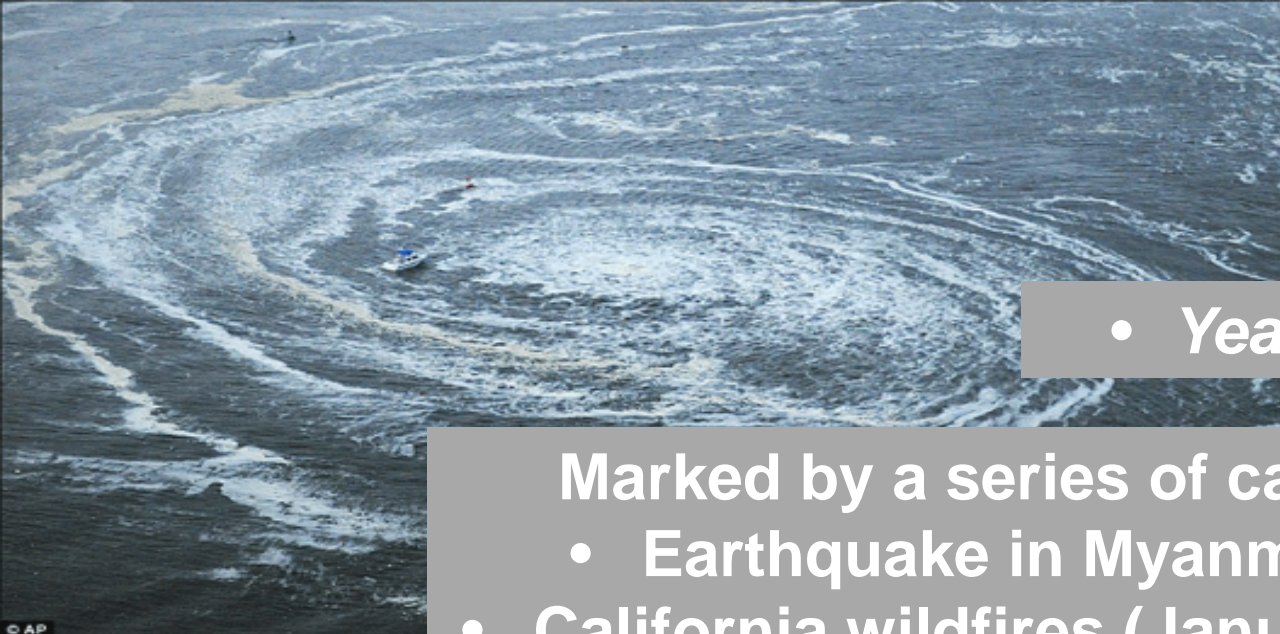
EM-DAT includes all disasters from 1900 until the present, conforming to at least one of the following criteria:

- 10 or more people dead;
- 100 or more people affected;
- The declaration of a state of emergency;
- A call for international assistance.



- *Year 2010: more than 295000 casualties and economic losses of more than 130000 millions of euros*
- *Year 2011: more than 30000 casualties and economic losses of more than 360000 millions of euros*





- *Year 2025:*

- Marked by a series of catastrophic natural hazards.
  - Earthquake in Myanmar (March 2025) deadliest.
  - California wildfires (January 2025) the most substantial economic damage, confirming annual economic losses >200 billion \$USD have become the new normal for the 2020s.

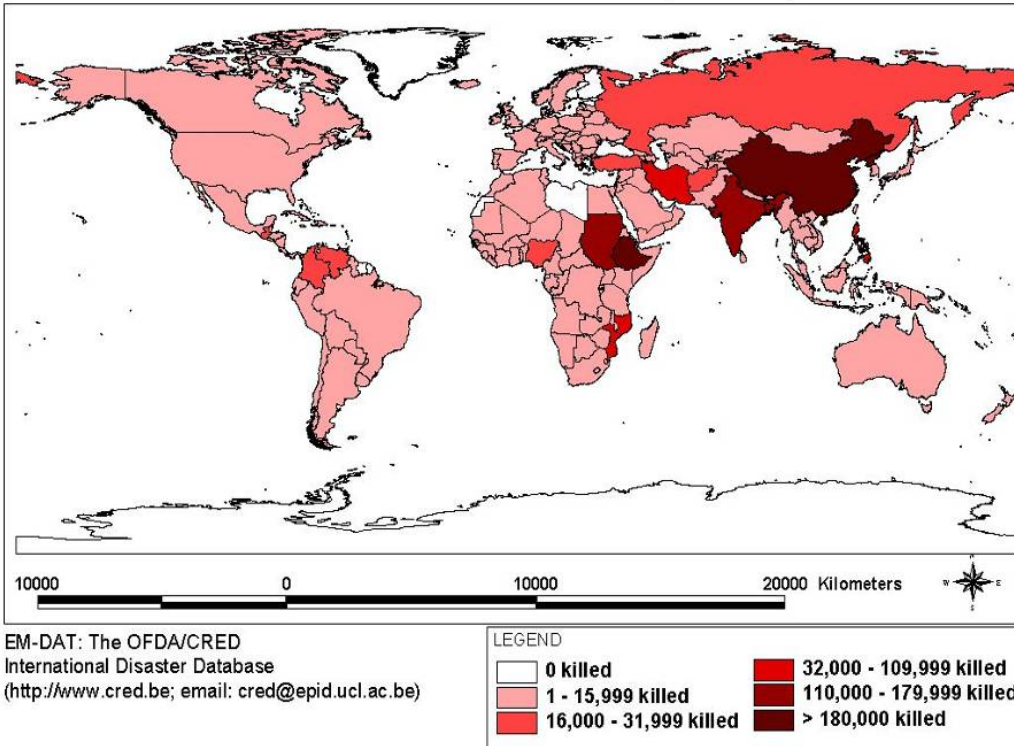


# Distribution of

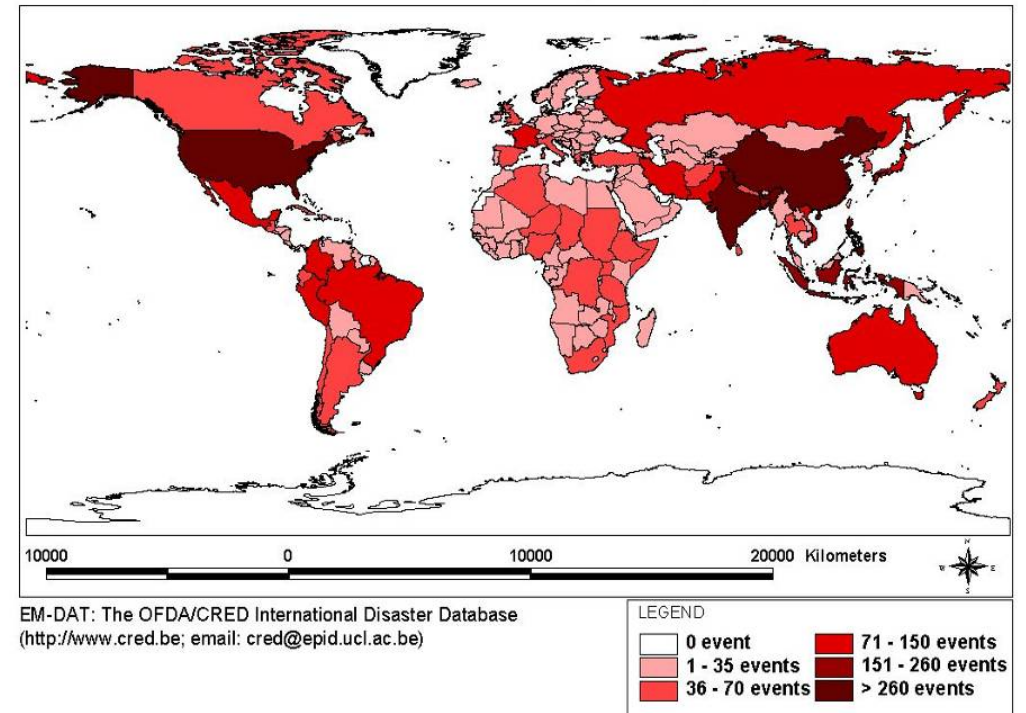
➤ natural disasters

➤ casualties

Distribution of natural disasters fatalities (1975-2001)



Distribution of natural disasters (1975-2001)



Number of casualties is more related to the **country vulnerability** than to the magnitude or the number of disasters

# The disaster cycle

- Mitigation / Preparation
- 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

- Build organizational capacity
- Emergency protocols
- Location of temporary shelters
- Prepositioning of supplies

- Structural analysis
- Strengthen buildings and infrastructures
- Prevention via modification of environmental conditions



- Rescue and evacuation operations
- Distribution of commodities
- Prevention of collateral damage
- Start of infrastructure recovery

- Recover preconditions
- Proxy Of funds
- Distribute post-disaster supplies
- Distribute humanitarian aid
- Infrastructures reconstruction

# Humanitarian vs. Commercial logistics

Characteristics	Commercial logistics	Humanitarian Logistics
Objective pursued	Minimize the logistic cost (inventory, transport,...)	Alleviate suffering
Demand	Known or estimated	Unpredictable in terms of timing, geographic location, type and quantity
Decision makers	Few decision makers	Multiple decision makers sometimes difficult to identify
Periodicity	Usually Repetitive	Sudden apparition of unexpected demand for large amounts.
Initial resources	Controlled	Lacking
Transportation network	Stable and functional	Can be damaged Dynamically changing
Uncertainty	Mainly due to demand, price or resources.	Additional uncertainty due to damaged structures, dependence on donations or safety concerns.

# Main components of decision-making processes for Humanitarian Logistics:

- Resource allocation policies
- Needs assessment
- Uncertainty of demand and supply
- Location for storage and shipment of goods
- Type of vehicle fleet and technology
- Uncertainty about routes and vehicles.

For example, according to experts, areas causing the biggest problems in the immediate response phase are:

- Coordination of receipt
- Unpredictability of demand
- The "last mile" to transport the aid to victims.

# Tools for humanitarian logistics

## ❑ **Crucial: effectiveness and efficiency**

To achieve efficiency and transparency in the management of available resources



Organizations involved in intervention  
require **new technologies and specific tools**

OR models / Decision Aid Systems



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# UCM-HUMLOG Decision Aid Models for Logistics and Disaster Management (Humanitarian Logistics)

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Ferrer JM, Martín-Campo FJ, Ortuño MT, Pedraza-Martínez AJ, Tirado G, Vitoriano B. (2018) Multi-criteria optimization for last mile distribution of disaster relief aid: Test cases and applications. EJOR 269 501-515

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UNION EUROPEA

Fondo Europeo de Desarrollo Regional

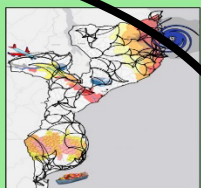
## Warehouses location and prepositioning

### Preparedness decisions with different time horizon:

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

### Model characteristics

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



Case Study: Mozambique

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## SEDD: Assessment of disaster consequences

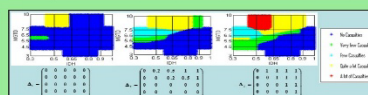
Disaster consequences > needs of the affected population > requirements of relief operations

### Just when a disaster strikes:

- uncertainty about what's happening;
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### FUZZY BIPOLAR CLASSIFICATION

Matrix	%CC	%NC	%TC	%ERROR	COST	PRED	VAR	P_DIF
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Avoid underestimation	50.52	0	50.52	49.48	0.9889	2.0181	1.339	0.2176



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### Fuel load and breaks management:

- Fuel-breaks location (ZAL)
- Prescribed burning

### Characteristics

- Uncertainty
- Propagation
- Networks connectivity
- Multiple criteria
- Risk management issues
- Environmental issues
- Resources allocation
- Metaheuristics



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Creation of long-term staff scheduling pre-disaster, and modification after disaster strikes minimizing the deviation to the schedule (disruption management)

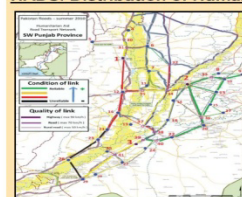
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Preparedness & Early Response

## HADS: Distribution of Humanitarian Aid



Case Study: Pakistan Floods 2010

**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
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Response

## Human evacuation

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

### Characteristics of the model:

- Multiple criteria
- Joint evacuation and commodities distribution
- Consideration of the gravity of the affected people

### Resolution:

Lexicographical goal programming with two priority levels:

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Emergencia en el Salvador, Cesal.org

## Forest fires: fire suppression

### Resources allocation and propagation:

- Uncertainty
- Networks connectivity

### Model characteristics:

- Multiple criteria
- Dynamic model
- Multistage Stochastic programming
- Simulator integration? Library?

Granda, B., Vitoriano, B., Figuera, J.R. (2025) A mathematical programming approach for a wildfire suppression problem. Operational Research 25, 1.  
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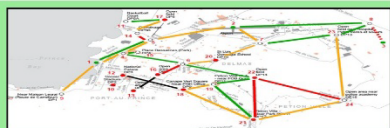
## REC-HADS: Recovery Operations

Links under some reliability level are considered unavailable. Joint infrastructure recovery and distribution flow model with:

- Recovery budget
- Criteria: Demand satisfied, time, security, reliability

### Criteria aggregation: Hierarchical Compromise Programming

Applications: Response phase during and after emergency



Case Study: Haiti Earthquake 2010

Liberatore, F., Vitoriano, B., Ortuño, M.T., Tirado, G., Scaparra, M.P. (2014) A hierarchical compromise model for the joint optimization of recovery operations and distribution of emergency goods in Humanitarian Logistics. Computers and Operations Research 42, 3-13.

## Staff planning for field hospitals

During response and recovery phases deployment of field hospitals may be necessary, with particularities in staff management. Creation of medical staff initial planning and rotations considering travel costs, volunaries availability and skills.

Martín-Campo, F.J., Ortuño, M.T., Ruiz-gonzález, B. (2025) Medical staff planning for field hospital deployments: the START hospital. Journal of Humanitarian Logistics and Supply Chain Management 15, 4-17.



Green Technologies

## Logistics with electric vehicles

### Optimal Routing and charging:

- Multiple technologies
- Partial Recharges



Felipe, A., Ortuño, M.T., Righini, G., Tirado, G. (2014) A heuristic approach for the green vehicle routing problem with multiple technologies and partial recharges. Transportation Research Part E: Logistics and Transportation Review 71, 111-128.  
Ceselli, A., Felipe, A., Ortuño, M.T., Righini, G., Tirado, G. (2021) A Branch and Cut and Price Algorithm for the Electric Vehicle Routing Problem with Multiple Technologies. Operations Research Forum 1, 2.

## Development: Photovoltaic Rural Electrification

- Remote areas: photovoltaic electrification
- Providing basic service (fee for service)
- Maintenance service by energy companies
- Planned: preventive maintenance
- Uncertainty: corrective maintenance, collecting fees

### Model:

1. Estimating cost and sizing
2. Obtaining simple rules for cost and sizing estimations



León, J., Martín-Campo, F.J., Ortuño, M.T., Vitoriano, B., Carrasco, L.M., Navarre, L. (2020) A methodology for designing electrification programs for remote areas. Central European Journal of Operations Research 28, 1265-1290.

General Logistics

## Transportation, Energy, Production...

- Power generation planning
- Railway transport
- Agriculture/Farm planning
- Orienteering problems
- Safety and Security
- Reliability
- ...



Tirado, G., Hvattum, L.M. (2017) Improved solutions to dynamic and stochastic maritime pick-up and delivery problems using local search. Annals of Operations Research 253, 825-843.

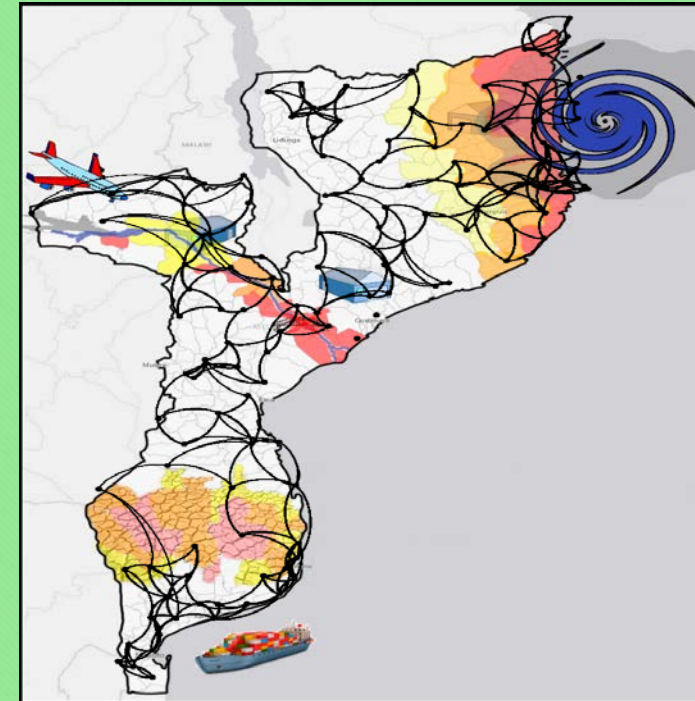
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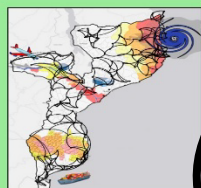
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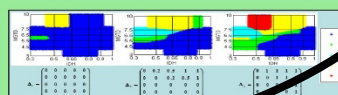
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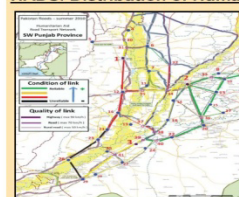
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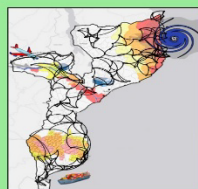
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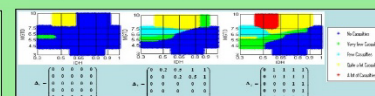
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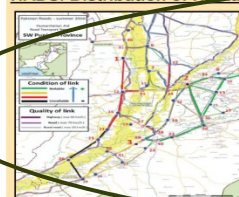
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Emergencia en el Salvador, Cesal.org

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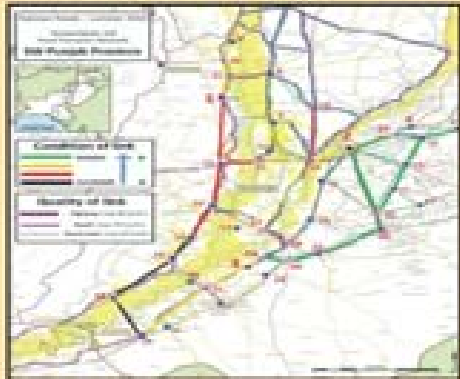
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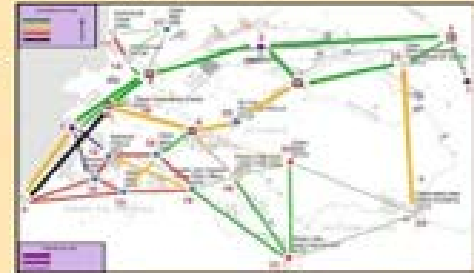
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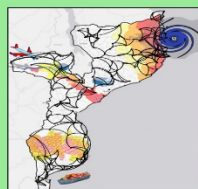
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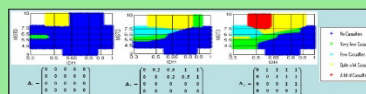
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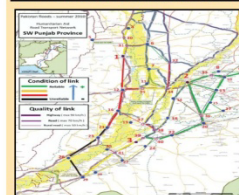
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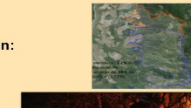
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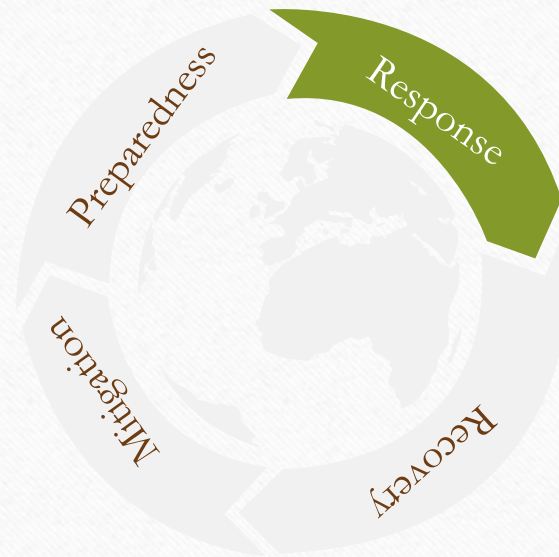
Source: Authors' own creation

# Last mile distribution problems

Last mile distribution is defined as the movement of goods from a transportation hub to the final delivery destination.

- Build organizational capacity
- Emergency protocols
- Location of temporary shelters
- Prepositioning of supplies

- Structural analysis
- Strengthen buildings and infrastructures
- Prevention via modification of environmental conditions



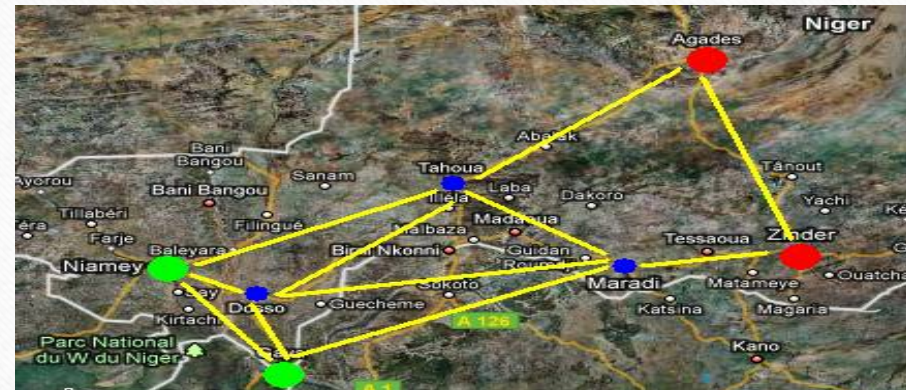
- Rescue and evacuation operations
- **Distribution of commodities**
- Prevention of collateral damage
- Start of infrastructure recovery

- Recover preconditions
- Proxy Of funds
- Distribute post-disaster supplies
- Distribute humanitarian aid
- Infrastructures reconstruction

# Elements of HADS (last mile distribution model)

1. **Logistic map:** network with nodes representing pick-up, connection or delivery places, main links characterised by

- Distance (length)
- Average speed
- Road state (reliability)
- Security level



2. **Goods (Water, food,...)**

- Available at each pickup node
- Demanded at each delivery node



# Elements of HADS (last mile distribution model)

## 3. Vehicles:

- Characteristics (Type):
  - Capacity
  - Speed
  - variable/fixed costs
  - compatibility with links
- Availability at each node



## 4. Mission goals:

- **Global quantity** to be distributed
- **Budget** available for operations

# CRITERIA

- **Effectiveness (Mission goal):**
  - Global quantity to be distributed
  - Budget
- **Equity** distribution of goods
- **Time of response**
- **Cost** (fix and variable)
- **Reliability (network state)**



# CRITERIA

## ➤ Security (assault):

Hip: the more vehicles traveling together less danger (convoys)

- Risk function based on the number of vehicles travelling
- Constraint: a link is used only once (driving together)



# Dealing with multiple Criteria

## ➤ Pareto Frontier:

Very difficult to obtain with so many objectives

- 2- and 3-dimensional projections
- Does not seem too useful for final users

## ➤ Reference point method

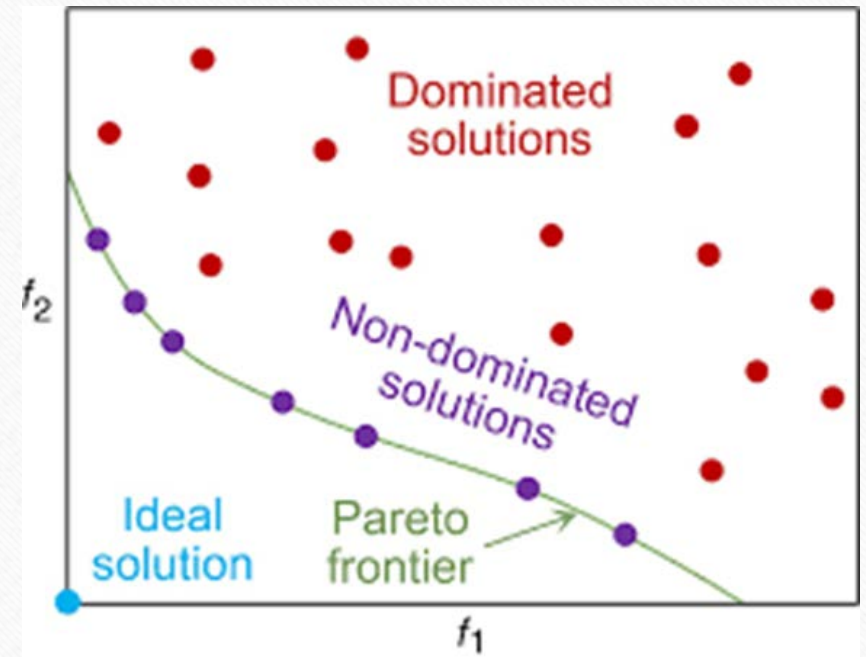
Minimizing distance to a reference point

- Set by decision maker (expert). Targets

(GOAL PROGRAMMING)

- Ideal point (optimum for each single criteria)

(COMPROMISE PROGRAMMING)



# Last mile distribution model

## PRIORITY LEVELS:

- 1. Hard constraints: higher priority**
  - Infeasible is not a solution
- 2. Soft constraints: goal constraints (targets)**

More priority levels:

Lexicographical Goal Programming Model

Level 1: mission goals (quantity distributed, budget)

Level 2: fit the other performance criteria to targets

## Static HADS:

- ❑ Load transported from  $i$  to  $j$  in vehicles of type  $k$   $QL_{ijk}$
- ❑ Load staying at  $i$  (delivered or not used)  $Q_i$
- ❑ Number of vehicles of type  $k$  going from  $i$  to  $j$   $NL_{ijk}$
- ❑ Number of vehicles of type  $k$  staying at  $i$   $N_{ik}$
- ❑ Time reaching node  $i$   $TM_i$
- ❑ Vehicles type  $k$  going from  $i$  to  $j$  ( $1=yes, 0=no$ )  $BL_{ijk}$

## Dynamic HADS: time horizon $T \ni t$

- ❑ Load going from  $i$  to  $j$  in vehicles type  $k$  beginning at  $t$   $QL_{ijkt}$
- ❑ Load at node  $i$  (delivered or not used) at time  $t$   $Q_{it}$
- ❑ Vehicles type  $k$  going from  $i$  to  $j$  beginning at  $t$   $NL_{ijkt}$
- ❑ Number of vehicles of type  $k$  staying at  $i$  at time  $t$   $N_{ikt}$

## Load Flow Constraints

### StaticHADS

$$\sum_k \sum_{i/(i,j) \in A} QL_{ijk} + av_j = \sum_k \sum_{i/(j,i) \in A} QL_{jik} + Q_j \quad \forall j \in N$$

$$Q_j \leq d_j + av_j \quad \forall j \in N$$

$$\sum_j Q_j = \sum_j av_j$$

### DynamicHADS

$$\sum_k \sum_{i/(i,j) \in A} \sum_{t' \leq t - tr_{ijk}} QL_{ijkt'} + av_j = \sum_k \sum_{i/(j,i) \in A} \sum_{t' \leq t} QL_{jikt'} + Q_{jt} \quad \forall j \in N, \forall t \leq T$$

$$Q_{jT} \leq d_j + av_j \quad \forall j \in N$$

$$\sum_j Q_{jT} = \sum_j av_j$$

## Vehicles Flow Constraints

### StaticHADS

$$\sum_{i/(i,j) \in A} NL_{ijk} + vav_{kj} = \sum_{i/(j,i) \in A} NL_{jik} + N_{jk} \quad \forall j \in N, \forall k$$

$$\sum_j N_{jk} = \sum_j vav_{kj} \quad \forall k$$

### DynamicHADS

$$\sum_{i/(i,j) \in A} \sum_{t' \leq t - tr_{ijk}} NL_{ijkt'} + vav_{kj} = \sum_{i/(j,i) \in A} \sum_{t' \leq t} NL_{jikt'} + N_{jkt} \quad \forall j \in N, \forall k, \forall t \leq T$$

$$\sum_j N_{jkT} = \sum_j vav_{kj} \quad \forall k$$

### Load-Lorries

#### StaticHADS

$$QL_{ijk} \leq cap_k NL_{ijk} \quad \forall (i, j) \in A, \forall k$$

#### DynamicHADS

$$QL_{ijkt} \leq cap_k NL_{ijkt} \quad \forall (i, j) \in A, \forall k, \forall t \leq T$$

# Subtours elimination constraints

## StaticHADS

$$TM_j \geq TM_i + tr_{ijk} - m \cdot (1 - BL_{ijk}) \quad \forall (i, j) \in A, \forall k$$
$$NL_{ijk} \leq m' \cdot BL_{ijk} \quad \forall (i, j) \in A, \forall k$$

## Operation constraints

### StaticHADS

$$COST = \sum_k \sum_{(i,j) \in A} l_{ij} (cv_{ijk} QL_{ijk} + 2cf_{kij} NL_{ijk}) \leq b$$
$$\sum_{i/d_i > 0} QF_i + Y_q = qglobal$$

### DynamicHADS

$$COST = \sum_{t \leq T} \sum_k \sum_{(i,j) \in A} l_{ij} (cv_{ijk} QL_{ijkt} + 2cf_{kij} NL_{ijkt}) \leq b$$
$$\sum_{i/d_i > 0} Q_{iT} + Y_q = qglobal$$

## Defining/computing attributes

- **COST:** already computed (budget)    **EQUITY:** worst demand unsatisfied

$$DX \geq 1 - \frac{Q_j}{d_j} \quad \forall j / d_j > 0$$

$$DX \geq 1 - \frac{Q_{jT}}{d_j} \quad \forall j / d_j > 0$$

- **TIME:** total time of operation

$$T_1 \geq TM_j \quad \forall j / d_j > 0$$

$$T_1 \geq t BQ_t \quad \forall t > tg_{T_1}$$

$$N_{jkt} - N_{jkT} \leq m_k'' BQ_t \quad \forall j, k, t$$

$$N_{jkT} - N_{jkt} \leq m_k'' BQ_t \quad \forall j, k, t$$

$$BQ_t \geq BQ_{t+1} \quad BQ_t \in \{0, 1\}$$

$$(m_k'' = \left( \sum_i vav_{ik} \right))$$

## Defining/computing more attributes

- **RANSACK Probability**

$$PS = \max_{\substack{(i,j) \in A / \\ \sum_k NL_{ijk} > 0}} p_{ij}^{\sum_k NL_{ijk}}$$

$$P_{MAX} = \ln PS = \max_{\substack{(i,j) \in A / \\ \sum_k NL_{ijk} > 0}} \ln p_{ij} \sum_k NL_{ijk}$$

$$P_{MAX} \geq \ln p_{ij} \sum_k NL_{ijk} + m'' \cdot (1 - BLT_{ij}) \quad \forall (i, j) \in A$$

$$P_{MAX} - DV_{P_{MAX}} \leq tg_{P_{MAX}}$$

## Defining/computing more attributes

- **RELIABILITY**

$$RMIN \leq r_{ij} + 1 - BLT_{ij} \quad \forall (i, j) \in A$$

$$RMIN + DV_{RMIN} \geq tg_{RMIN}$$

- **PRIORITY (Node L)**

$$\frac{QF_L}{d_L} + DV_P \geq tg_P$$

# Lexicographical Model

$$\text{Lex min } a = \left[ \left( Y_q \right), \left( \sum_{g=1}^3 w_g DV_g \right) \right]$$

*Level 1:*

$$Y_q^* = \min Y_q$$

$$\text{s.a. } \sum_{j \in N/d_j > 0} Q_{jT} + Y_q = q_{\text{global}}$$

$$Y_q \geq 0$$

and rest of hard constraints

*Level 2:*

$$\min w_C DV_C + w_E DV_E + w_{T_1} DV_{T_1}$$

$$\text{s.a. } \sum_{j \in N/d_j > 0} Q_{jT} + Y_q^* = q_{\text{global}}$$

$$COST - DV_C \leq tg_C$$

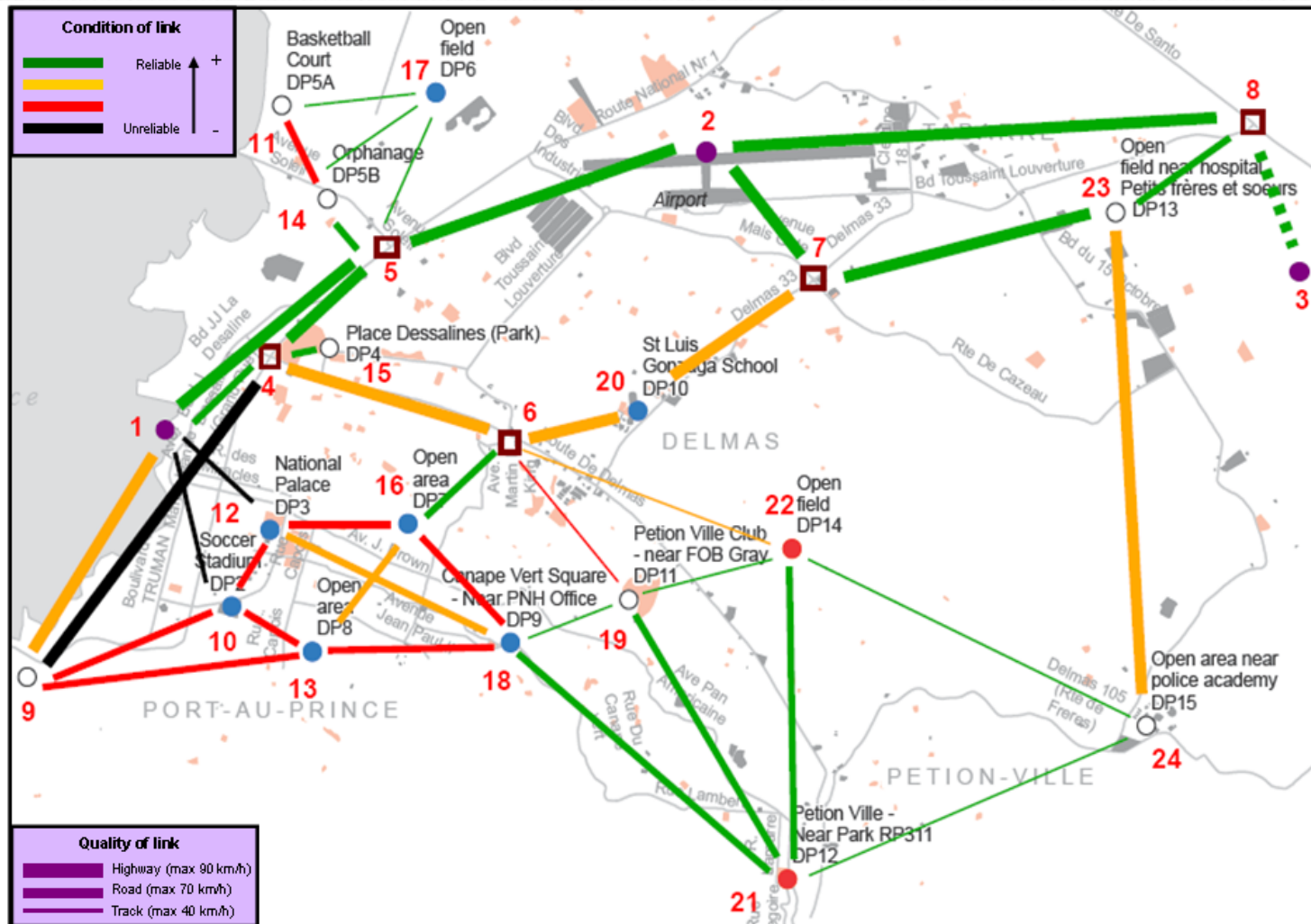
$$T_1 - DV_{T_1} \leq tg_{T_1}$$

$$DX - DV_{DX} \leq tg_{DX}$$

$$DV_g \geq 0 \quad g = C, DX, T_1$$

hard constraints, and computing attributes

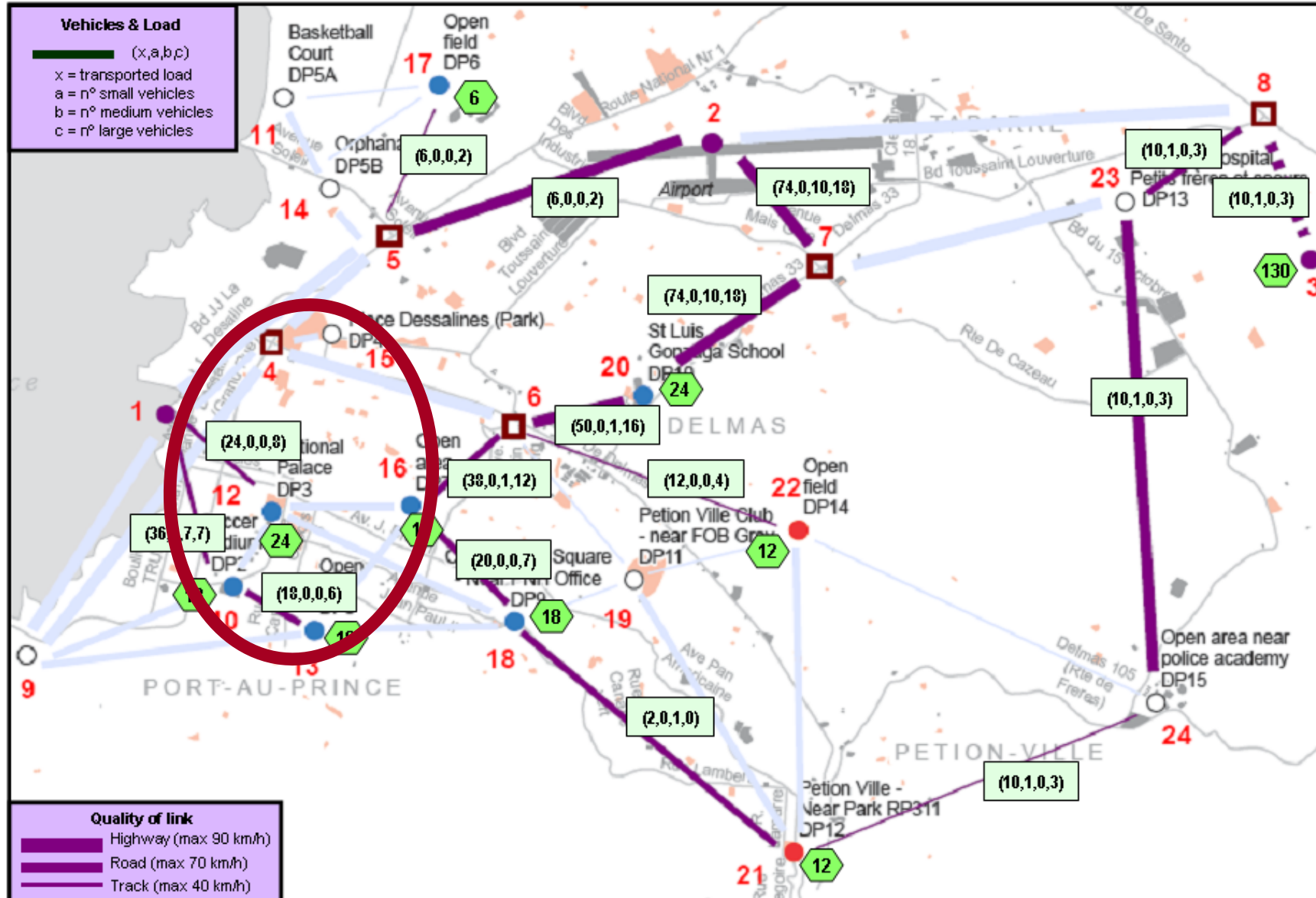
# Case study: Haiti (Hearthquake 2010)



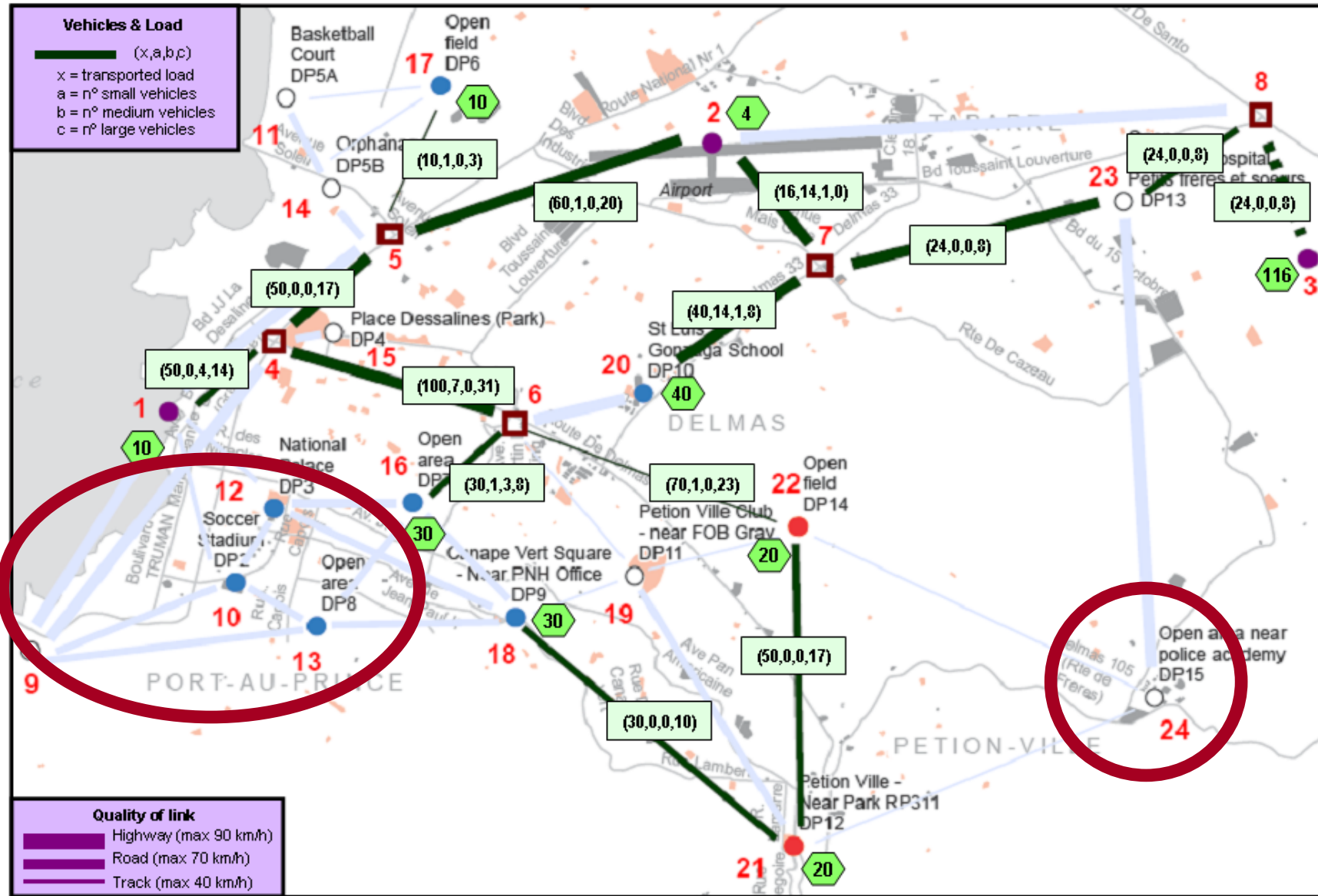
- ✓ Nodes: 24 (3 supply –port: airport: border-; 9 demand)
- ✓ Arcs : 42 (84 one way)
- ✓ Total demand: 250 Tm.
- ✓ Total supply: 280 Tm.
- ✓  $Q_{global}$ : 150 Tm (60%)
- ✓ Budget: 80000€
- ✓ Vehicles: 3 types [135, 95, 70 vehicles of each type]
  - Capacity: 1, 2 and 3 Tms
  - Speed: 100, 80 and 60 Km/h
  - Not all on supply nodes.



# Equitable Itinerary:



# Maximum reliability Itinerary:





# Evacuation at the humanitarian Logistics cycle

Evacuation consists on moving people and assets temporarily to safer places before, during or after the occurrence of a hazardous event in order to protect them

- Build organizational capacity
- Emergency protocols
- Location of temporary shelters
- Prepositioning of supplies

- Structural analysis
- Strengthen buildings and infrastructures
- Prevention via modification of environmental conditions



- **Rescue and evacuation operations**
- **Distribution of commodities**
- Prevention of collateral damage
- Start of infrastructure recovery

- Recover preconditions
- Proxy Of funds
- Distribute post-disaster supplies
- Distribute humanitarian aid
- Infrastructures reconstruction

# Evacuation routes

According to the London Resilience Partnership (2018) the following forms of evacuation are possible:

- ✓ **Self-Evacuation:** individuals make their own arrangements to move from place of danger to safe place using existing public transport or their own mode of transportation.
- ✓ **Assisted Evacuation:** individuals are capable of transporting themselves but require support (indications, etc.)
- ✓ **Supported Evacuation:** individuals require support from the emergency services and public authorities to move from the place of danger or threat of danger. This is likely to have been preceded by the identification of the vulnerable. Support could be in many forms and is likely to require special transport arrangements to cater for the vulnerable.





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Invited Review

### Optimising shelter location and evacuation routing operations: The critical issues

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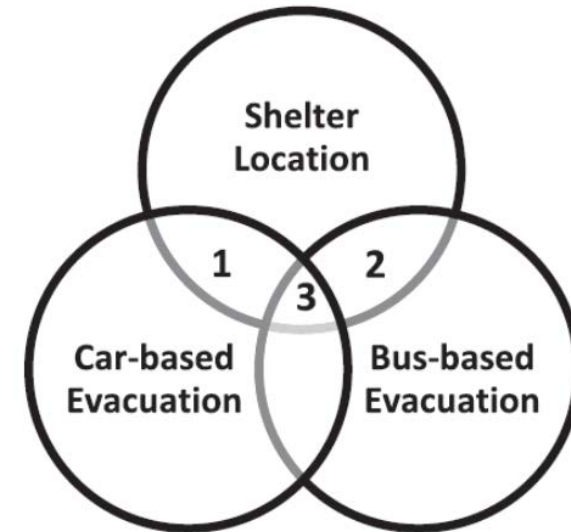
Evacuation routing

Optimisation

ABSTRACT

Shelter opening and evacuation of vulnerable populations are operations crucial to disaster response, which is one of the four phases of Disaster Operations Management (DOM). Optimisation has tried to capture some of the different issues related to shelter location and evacuation routing have been developed over the years. However, they are still far from being fully covered. The main goal of this paper is to identify the current challenges in devising realistic and applicable in the shelter location and evacuation routing context, with the ultimate goal of our future research in this topical area. A critical analysis of the most recent combined including insights from the authors of the existing papers. The analysis highlights research opportunities, such as the need for future optimisation models to involve evacuee as well as system behaviour, be application-oriented rather than theoretical interdisciplinary.

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Article

### Supported Evacuation for Disaster Relief through Lexicographic Goal Programming

Inmaculada Flores<sup>1,2,\*</sup>, M. Teresa Ortuño<sup>1,2</sup> and Gregorio Tirado<sup>2,3</sup> and Begoña Vitoriano<sup>1,2</sup>

A goal programming model for early evacuation of vulnerable people and relief distribution during a wildfire

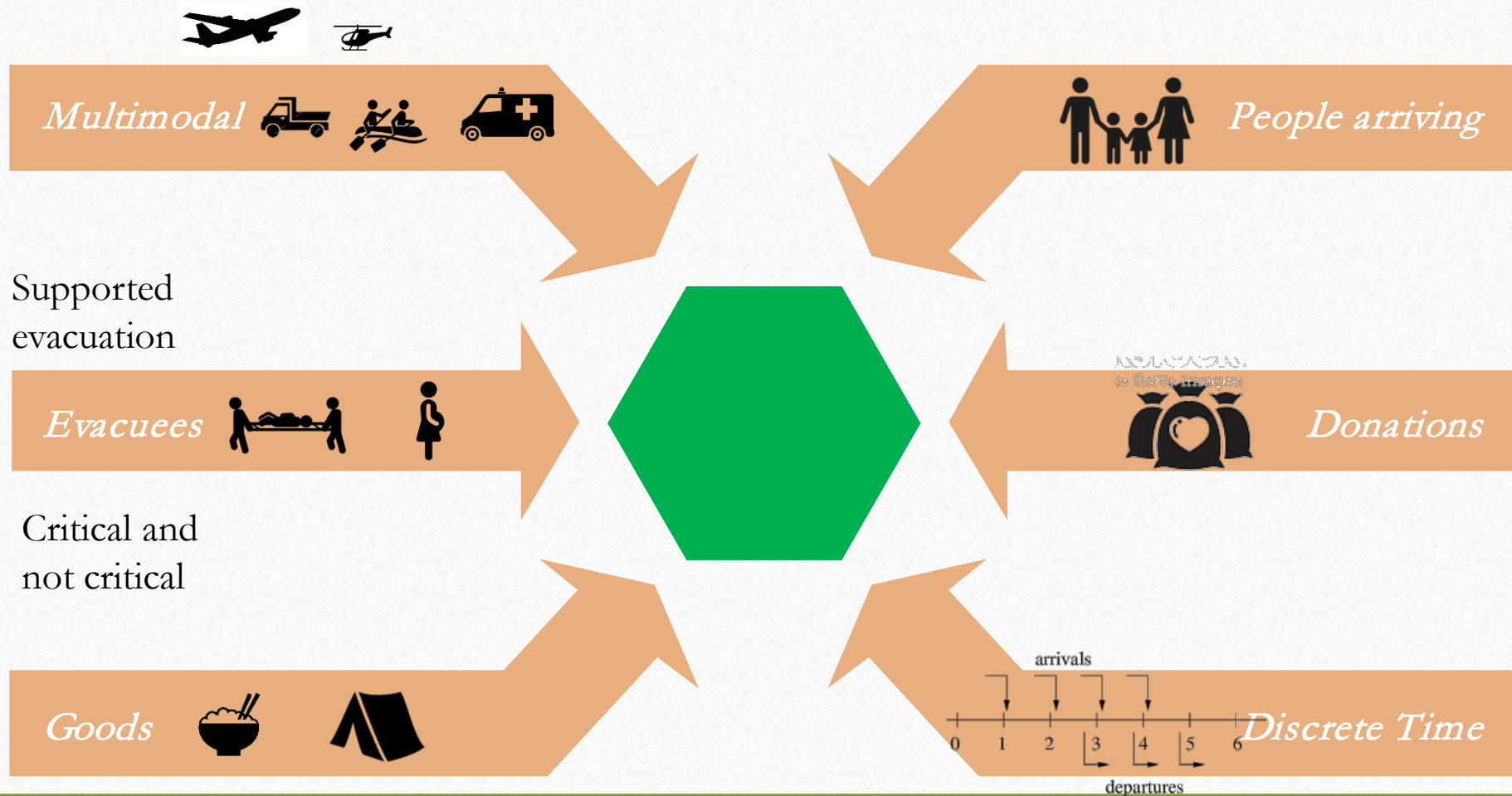
Inmaculada Flores<sup>a,c,\*</sup>, M. Teresa Ortuño<sup>a,c</sup>, Gregorio Tirado<sup>b,c</sup>

<sup>a</sup> Faculty of Mathematical Sciences, Complutense University of Madrid, Spain

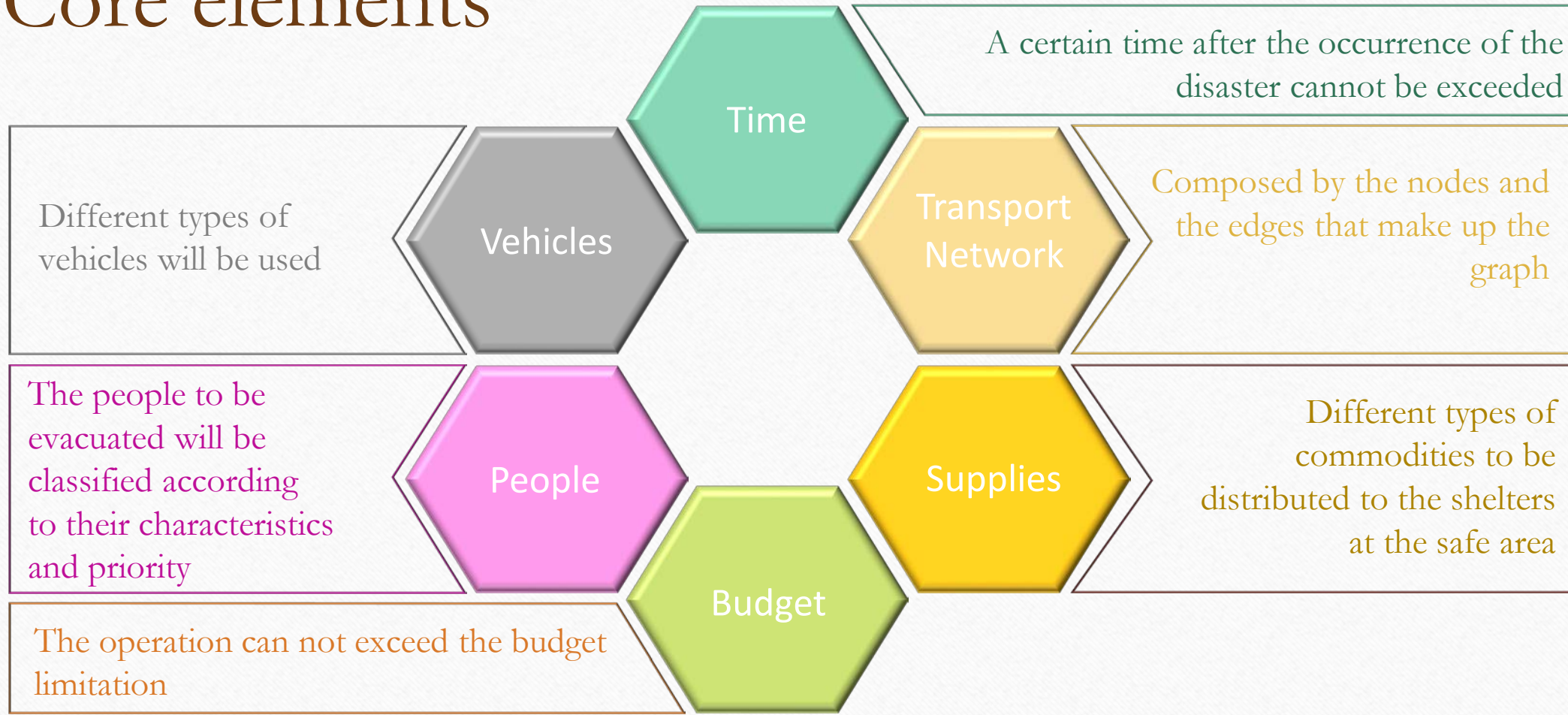
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<sup>c</sup> Interdisciplinary Mathematics Institute, Complutense University of Madrid, Spain

# Model characteristics



# Core elements



# Variables of the model

$\mathbb{Z}^+$   
 $\forall i, j, k, h, t$

$Tot_p$  maximum number of critical population that can be evacuated

$Tot_N$  maximum number of non critical population that can be evacuated

$Q_{hit}$  amount of people type  $h$  in  $i$  at the beginning of  $t$

$QL_{hijkt}$  amount of people type  $h$  who start to travel  $(i,j)$  in  $k$  at the beginning of  $t$

$N_{ikt}$  amount of vehicles type  $k$  in  $i$  at the beginning of  $t$

$NL_{ijkt}$  amount of vehicles type  $k$  that start to travel  $(i,j)$  at the beginning of  $t$

$TTotPri$  total time needed to evacuate the population with high priority

$TTot$  total time needed to evacuate the population with normal priority

$0 \leq$   
 $\forall i, j, k, c, t$

$CO_{cit}$  number of supplies type  $c$  at node  $i$  at the beginning of  $t$

$COL_{cijkt}$  number of supplies type  $c$  that start the movement from  $i$  to  $j$  at the beginning of  $t$

$CONS_{cit}$  number of supplies of type  $c$  consumable that are consumed

$UTIL_{cit}$  number of supplies of type  $c$  non consumable that are utilized

$INS_{cit}$  unsatisfied consumption of supplies of type  $c$  during period  $t$

$CI$  weighted sum of unsatisfied consumption

$DV_m$  deviation, respect to each aspirational level of goal  $m$

$P_m$  slack variable

$Cost$  total cost of the operation

$\{0,1\}$   
 $\forall t$

$BTH_t$  1 if the high priority population has been evacuated in period  $t$  and 0, otherwise

$BT_t$  1 if the entire population has been evacuated in period  $t$  and 0, otherwise

# Mathematical multicriteria model

## Objectives:

- Maximize the number of critical evacuees (**TotP**)
- Maximize the number of non critical evacuees (**TotN**)
- Minimize the evacuation time for critical evacuees (**TtotPri**)
- Minimize the evacuation time for non critical evacuees (**Ttot**)
- Minimize the cost (**Cost**) ➤ Minimize the unsatisfied consumption (**CI**)

## Three levels to be optimized lexicographically:

- **Level 1:** To evacuate to the greater amount possible of affected population (weighted sum of critical and non critical)
- **Level 2:** To adjust the time of the evacuation of critical population
- **Level 3:** Weighted sum between total cost and time and unsatisfied consumption of supplies

$$\text{Lexmin} \left\{ \left[ \frac{\alpha_P DV_P}{tg_P} + \frac{\alpha_N DV_N}{tg_N} \right], [DV_{TP}], \left[ \frac{\alpha_{Cte} DV_{Cte}}{tg_{Cte}} + \frac{\alpha_{TT} DV_{TT}}{tg_{TT}} + \frac{\alpha_{CI} DV_{CI}}{tg_{CI}} \right] \right\}$$

# Constraints at the model

People flow

$$\sum_{j|dist_{jik}>0} \sum_k \sum_{t' \leq t - tr_{jik}} QL_{hjikt'} + \sum_{t' \leq t} evacu_{hit'} =$$

$$= \sum_{j|dist_{ijk}>0} \sum_k \sum_{t' \leq t} QL_{hijkt'} + Q_{hit} \quad \forall h, i, t$$

Capacity

$$w_h Q_{hit} \leq qav_{hi} \quad \forall t, h, i \in \mathcal{NH} \cup \mathcal{NR}$$

$$\sum_h w_h QL_{hijkt} \leq cap_k NL_{ijkt} \quad \forall i, j|dist_{ijk} > 0 \quad \forall k, t$$

Number of persons

$$Tot_P = \sum_{i \in \mathcal{NH} \cup \mathcal{NR}, h|p(h)=\max_h\{p(h)\}} Q_{hiT}$$

$$Tot_N = \sum_{i \in \mathcal{NH} \cup \mathcal{NR}, h|p(h)=\min_h\{p(h)\}} Q_{hiT}$$

Vehicles flow

$$\sum_{j|dist_{jik}>0} \sum_{t' \leq t - tr_{jik}} NL_{jikt'} + vav_{ik} =$$

$$= \sum_{j|dist_{ijk}>0} \sum_{t' \leq t} NL_{ijkt'} + N_{ikt} \quad \forall i, k, t$$

$$\sum_i vav_{ik} = \sum_i N_{ikT} \quad \forall k$$

# Constraints at the model

Supplies flow

$$\sum_{j|dist_{jik}>0} \sum_k \sum_{t' \leq t - tr_{jik}} COL_{cjikt'} + \sum_{t' \leq t} com_{cit'} - \sum_{j|dist_{ijk}>0} \sum_k \sum_{t' \leq t} COL_{cijkt'} \geq \sum_{t' \leq t} CONS_{cit'} \quad \forall t, c | gasta_c = 1, i \in \mathcal{NH} \cup \mathcal{NR}$$

$$\sum_{j|dist_{jik}>0} \sum_k \sum_{t' \leq t - tr_{jik}} COL_{cjikt'} + \sum_{t' \leq t} com_{cit'} - \sum_{j|dist_{ijk}>0} \sum_k \sum_{t' \leq t} COL_{cijkt'} = UTIL_{cit} \quad \forall t, c | gasta_c = 0, i \in \mathcal{NH} \cup \mathcal{NR}$$

$$\sum_{j|dist_{jik}>0} \sum_k \sum_{t' \leq t - tr_{jik}} COL_{cjikt'} = \sum_{j|dist_{ijk}>0} \sum_k \sum_{t' \leq t} COL_{cijkt'} \quad \forall c, t, i \in \mathcal{NA} \cup \mathcal{NT}$$

$$\sum_h con_{hc} Q_{hit} = CONS_{cit} + INS_{cit} \quad \forall t, c | gasta_c = 1, i \in \mathcal{NH} \cup \mathcal{NR}$$

$$\sum_h con_{hc} Q_{hit} \leq UTIL_{cit} + INS_{cit} \quad \forall t, c | gasta_c = 0, i \in \mathcal{NH} \cup \mathcal{NR}$$

$$CI = \sum_{c,i,t} \alpha_{ci} INS_{cit}$$

Supplies consumption

# Constraints at the model

Supplies to be stocked and capacities

$$CO_{cit} = \sum_{j|dist_{jik}>0} \sum_k \sum_{t' \leq t - tr_{jik}} COL_{cjikt'} + \sum_{t' \leq t} com_{cit'} - \\ - \sum_{j|dist_{ijk}>0} \sum_k \sum_{t' \leq t} COL_{cijkt'} - \sum_{t' \leq t} CONS_{cit'} \forall t, c | gasc_c = 1, i \in \mathcal{NH} \cup \mathcal{NR}$$

$$CO_{cit} = UTIL_{cit} \forall t, c | gasc_c = 0, i \in \mathcal{NH} \cup \mathcal{NR}$$

$$\sum_c w_c CO_{cit} \leq \sum_c qac_{ci} \quad \forall i, t$$

$$\sum_c w_c COL_{cijkt} \leq cap_k NL_{ijkt} \quad \forall i, j | dist_{ijk} > 0 \quad \forall k, t$$

$$Cost = \sum_{h,c,i,j,k,t|dist_{ijk}>0} dist_{ijk} (cf_{ijk} NL_{ijkt} + cv_{ijk} (QL_{hijkt} + COL_{cijkt}))$$

$$Cost \leq b$$

Cost

# Constraints at the model

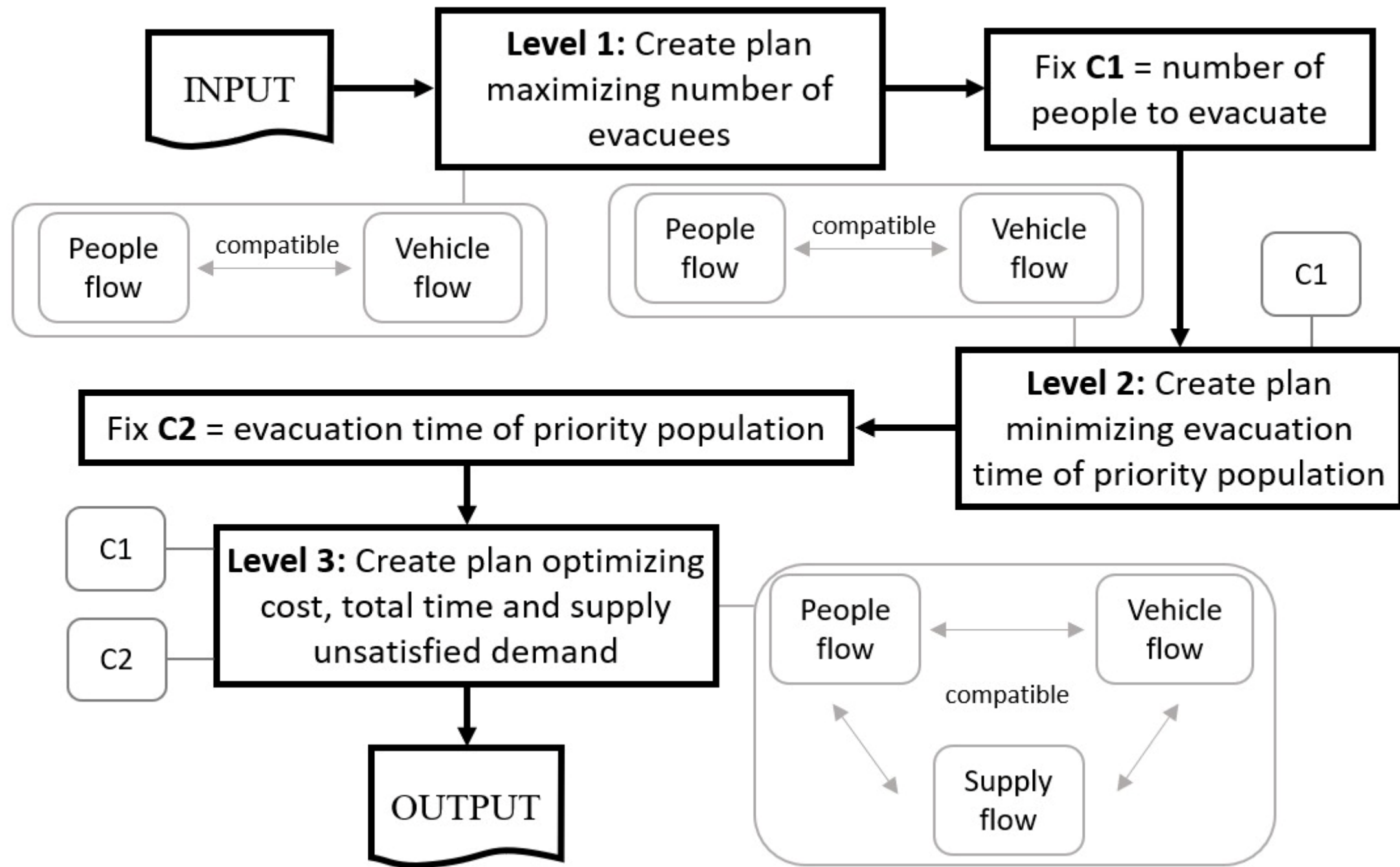
Time of evacuation of critical persons

$$T_{totPri} = \sum_t t(BTH_t - BTH_{t-1})$$
$$BTH_t \geq BTH_{t-1} \quad \forall t$$
$$\sum_{h|p(h)=\max_h\{p(h)\}} \sum_{i,j|dist_{ijk}>0} \sum_k \sum_{t'|t'=\lceil t-tr_{ijk} \rceil} QL_{hijkt'} \leq totevac_P(1 - BTH_t) \quad \forall t$$

$$T_{tot} = \sum_t t(BT_t - BT_{t-1})$$
$$BT_t \geq BT_{t-1} \quad \forall t$$
$$\sum_{h|p(h)=\min_h\{p(h)\}} \sum_k \sum_{i,j|dist_{ijk}>0} \sum_{t'|t'=\lceil t-tr_{ijk} \rceil} QL_{hijkt'} \leq totevac_N(1 - BT_t) \quad \forall t$$

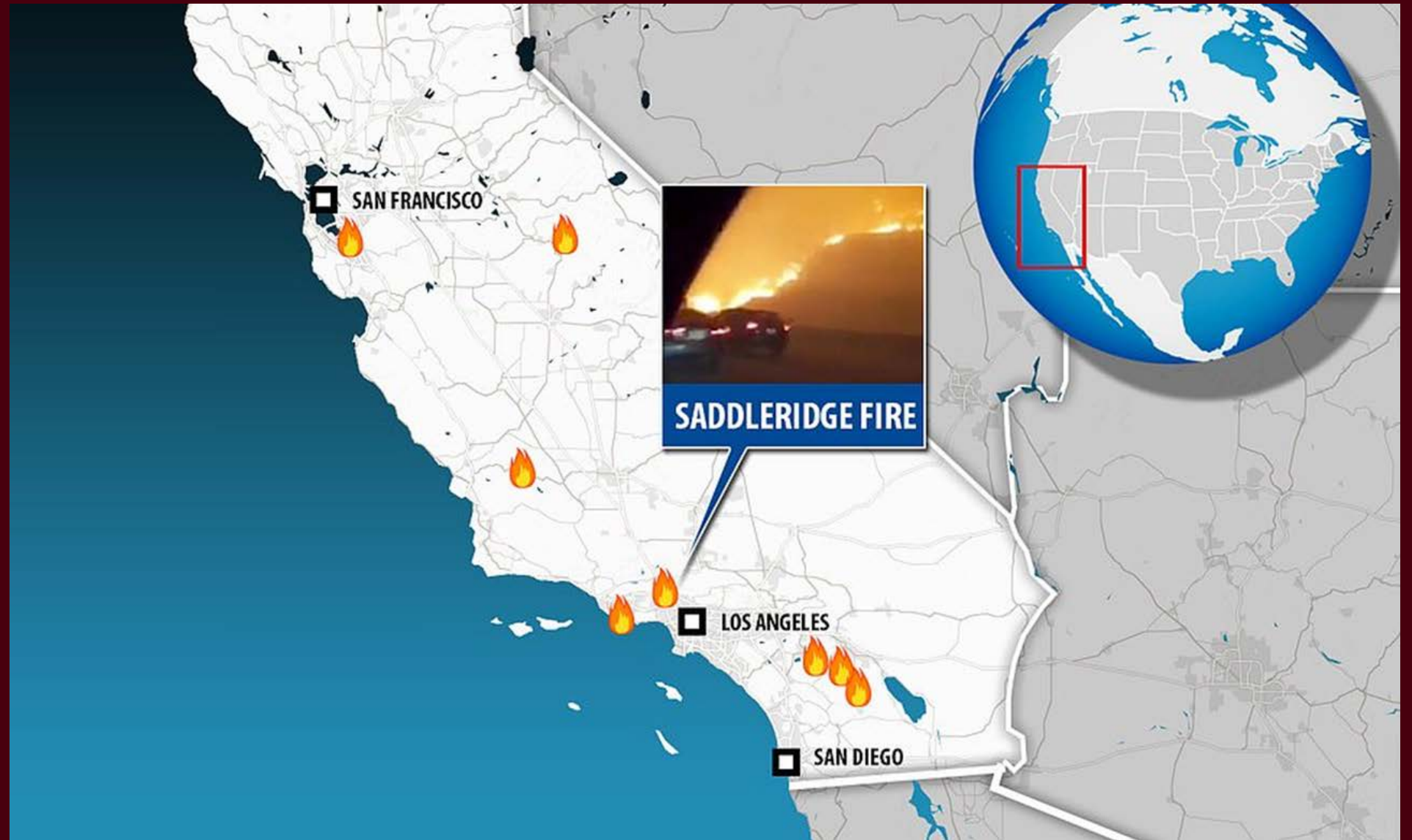
Time of evacuation of non critical persons

- + Goals deviation
- + Variables domain

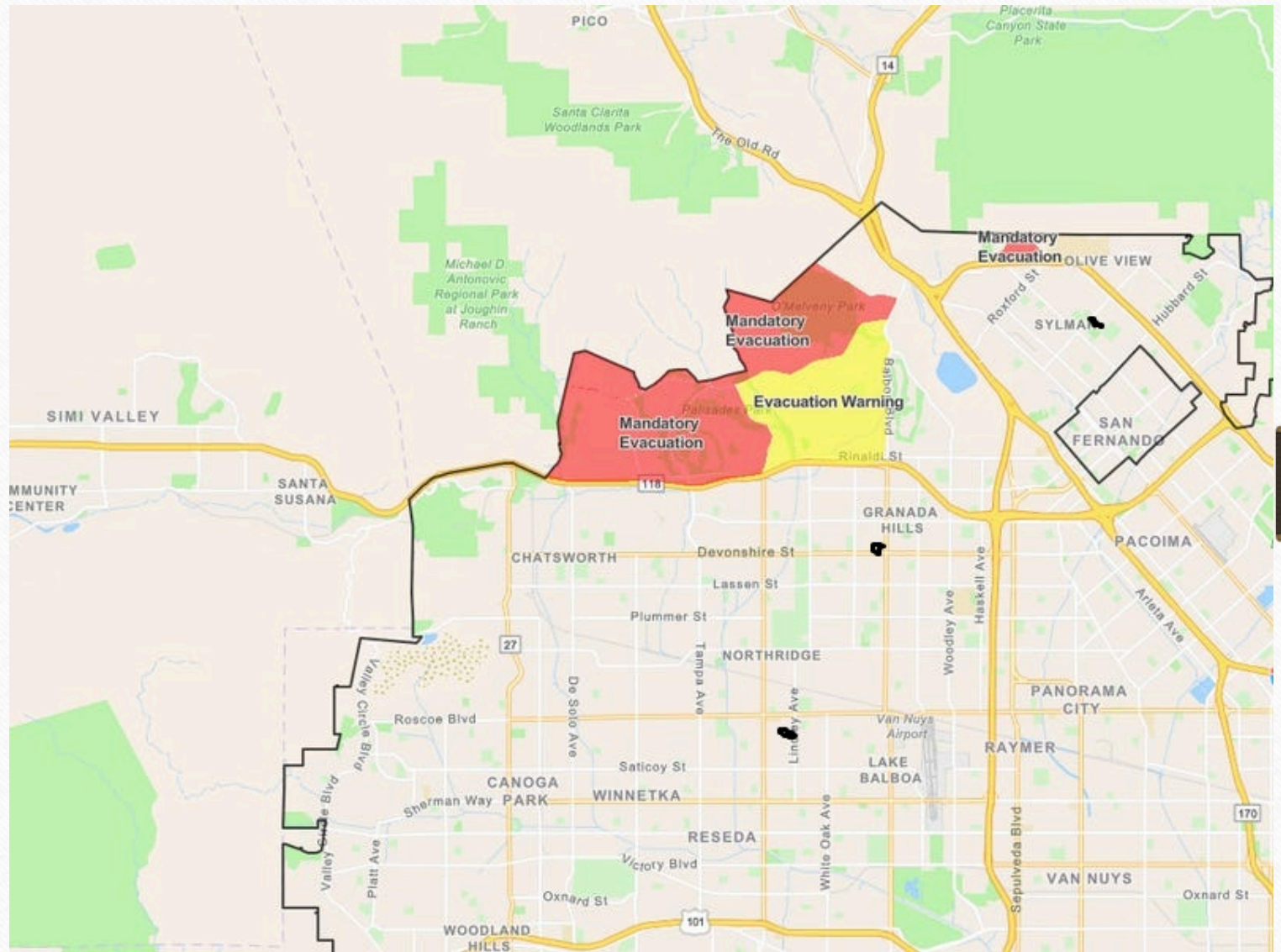


# Saddleridge fire (Oct 2019)

San  
Fernando  
Valley,  
Los  
Angeles  
County,  
California.



Up to 23,000 homes were placed under mandatory evacuation, leaving over 100,000 residents displaced at the fire's peak.





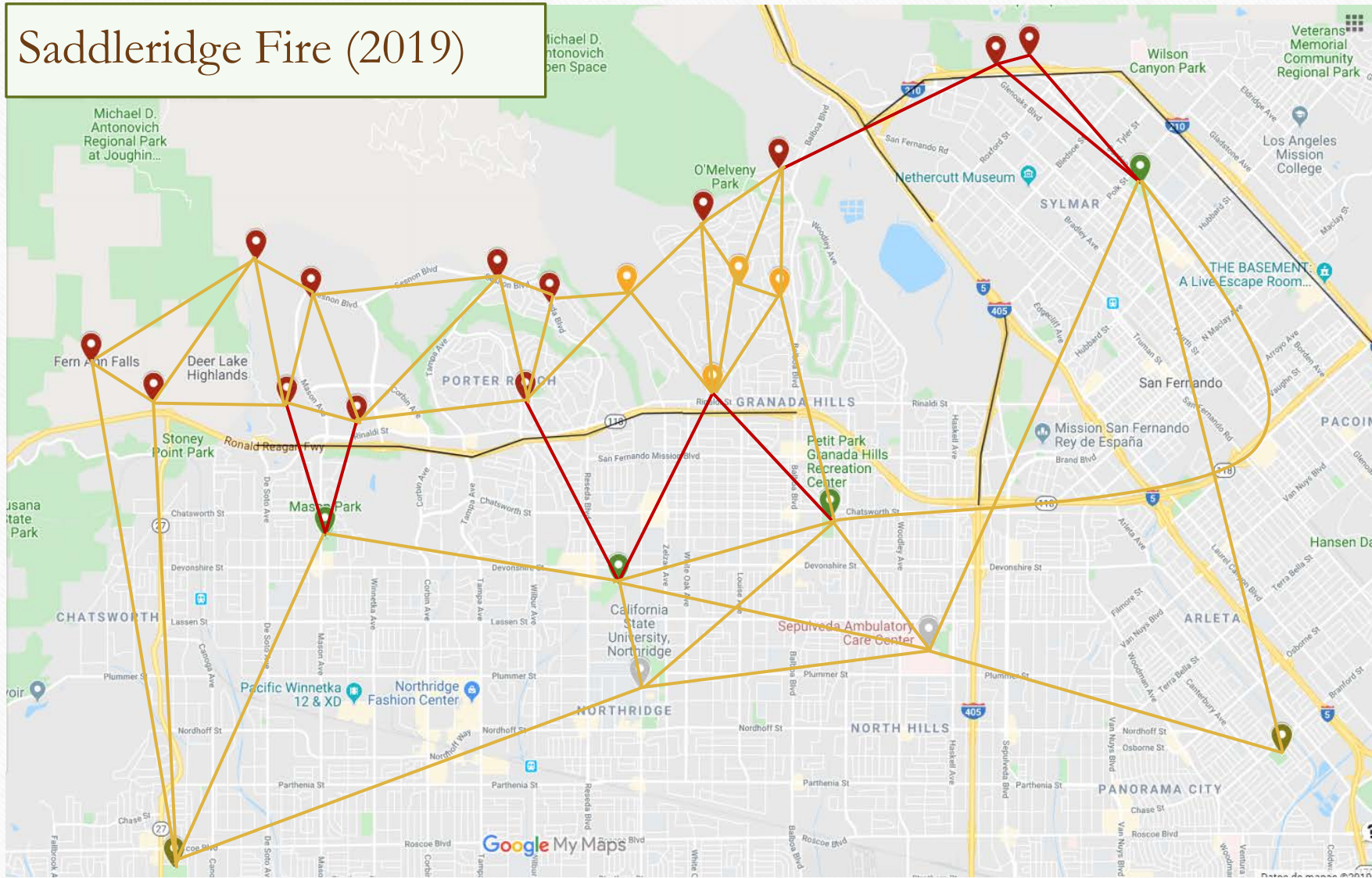
**American  
Red Cross**

[https://youtu.be/6HHaaJ7m\\_qA](https://youtu.be/6HHaaJ7m_qA)

## Red Cross opens shelters for those Affected by Saddleridge Fire

- Red Cross emergency shelters are designed to meet the immediate, short-term needs of impacted residents until long-term efforts can get underway. In 3 days:
  - ✓ Opened four shelters
  - ✓ Provided more than 440 shelter stays
  - ✓ Served more than 3,200 meals and snacks
  - ✓ Distributed more than 490 comfort kits

# Saddleridge Fire (2019)

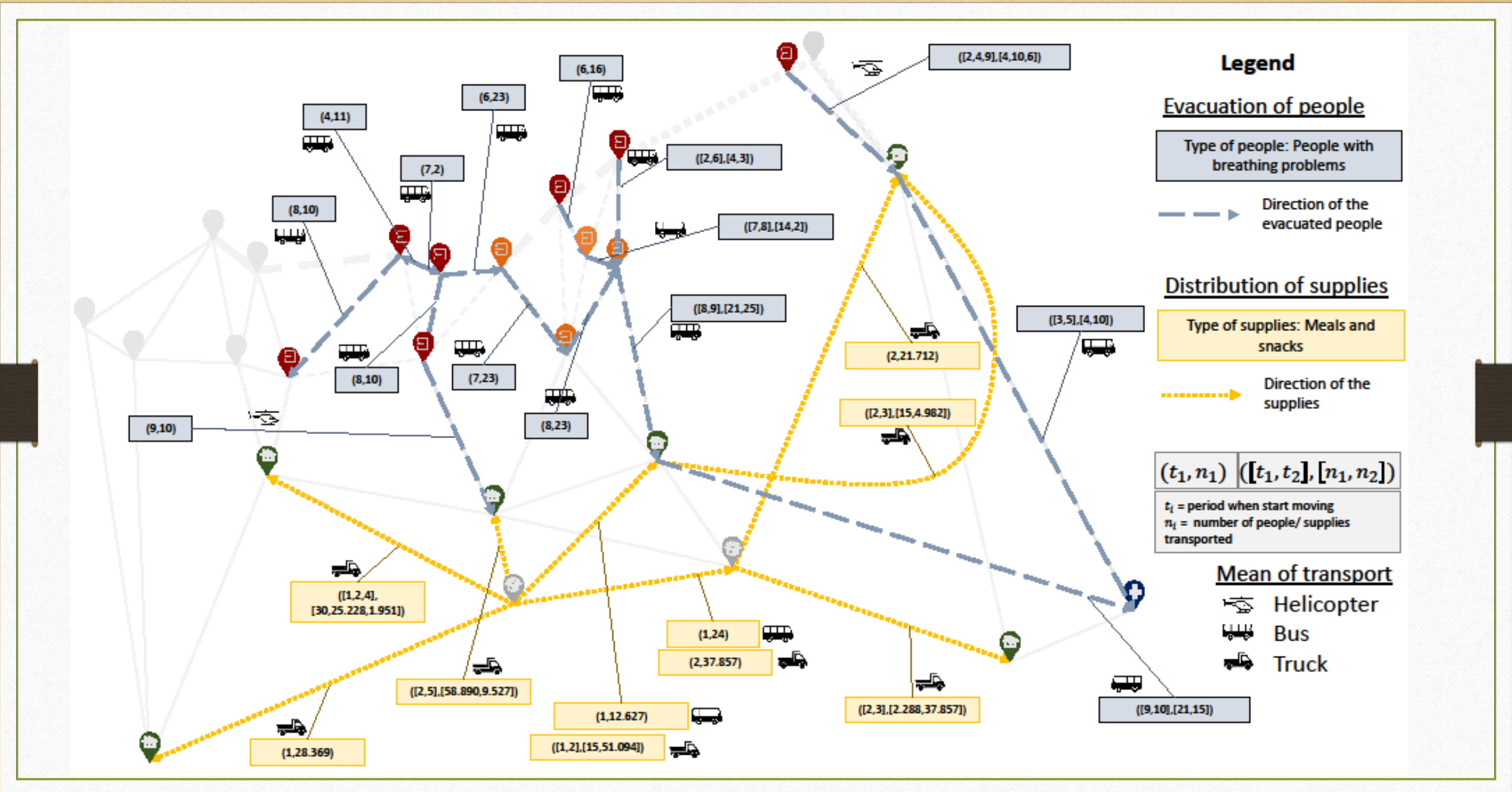


**Legend: Road status**  
 Blocked or shattered  
 Alternate helicopter route  
 Terrestrial road

**Node type**

- Pickup-ME Area
- Pickup-WE Area
- Primary shelter
- Secondary shelter
- Depot

# Example: evacuation plan for people with breathing problems



**1** OR for the Common Good

**2** Disaster management. Humanitarian Logistics

**3** Some OR Models for HL

**4** Case Studies

**5** Conclusions

# Case studies

Key point to achieve validation and credibility

- Niger famine (2005)
- Haiti earthquake (2010)
- Pakistan floods (2010)
- Indonesia floods (2018)

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**Multi-criteria optimization for last mile distribution of disaster relief aid: Test cases and applications**

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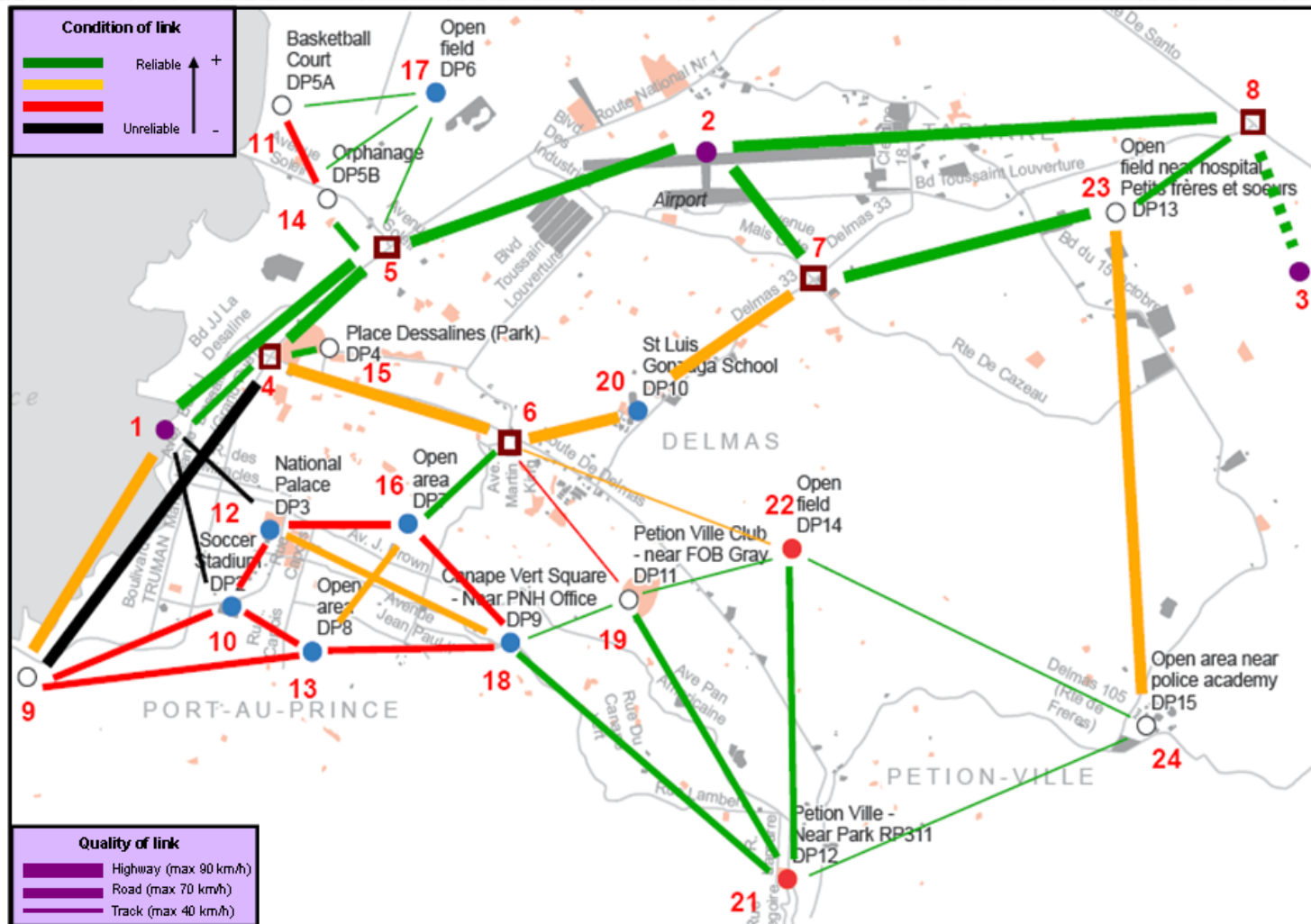
**ABSTRACT**

Humanitarian organizations transport large quantities of aid for distribution in the aftermath of disasters. Transportation for last mile distribution includes multiple, and often conflicting, performance criteria that include time (deprivation), cost, coverage, equity and security. We build a compromise programming model for multi-criteria optimization in humanitarian last mile distribution. Regarding security, ours is the first multi-criteria model able to produce an actual vehicle schedule while forcing vehicles to form convoys in humanitarian operations research. We illustrate the multi-criteria optimization using a realistic test case based on the Pakistan floods, 2010. We standardize and share this case as well as cases based on the Niger famine, 2005 and the Haiti earthquake, 2010. By sharing test cases, we encourage basic scientific tasks such as replicability and model comparison within the humanitarian operations research community.

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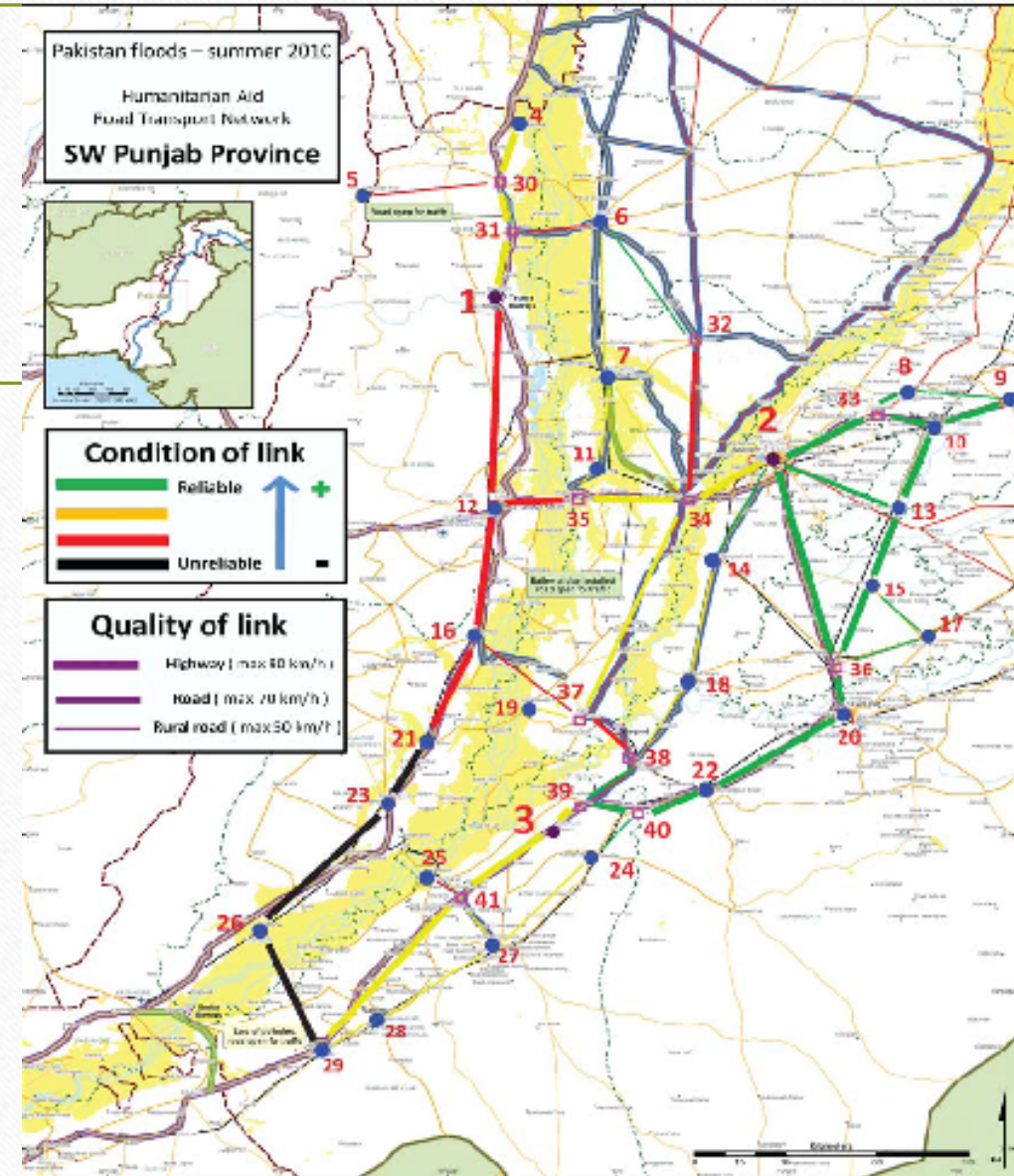


# Case study: Haiti (Hearthquake 2010)



- ✓ Nodes: 24 (3 supply –port: airport: border-; 9 demand)
- ✓ Arcs : 42 (84 one way)
- ✓ Total demand: 250 Tm.
- ✓ Total supply: 280 Tm.
- ✓  $Q_{global}$ : 150 Tm (60%)
- ✓ Budget: 80000€
- ✓ Vehicles: 3 types [135, 95, 70 vehicles of each type]
  - Capacity: 1, 2 and 3 Tms
  - Speed: 100, 80 and 60 Km/h
  - Not all on supply nodes.

# Case of study: Pakistan floods (2010)

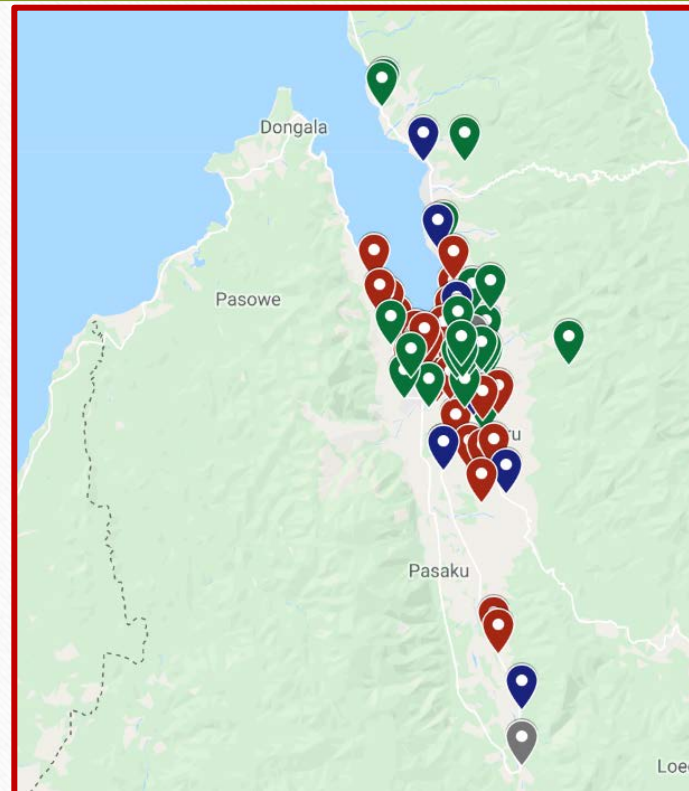
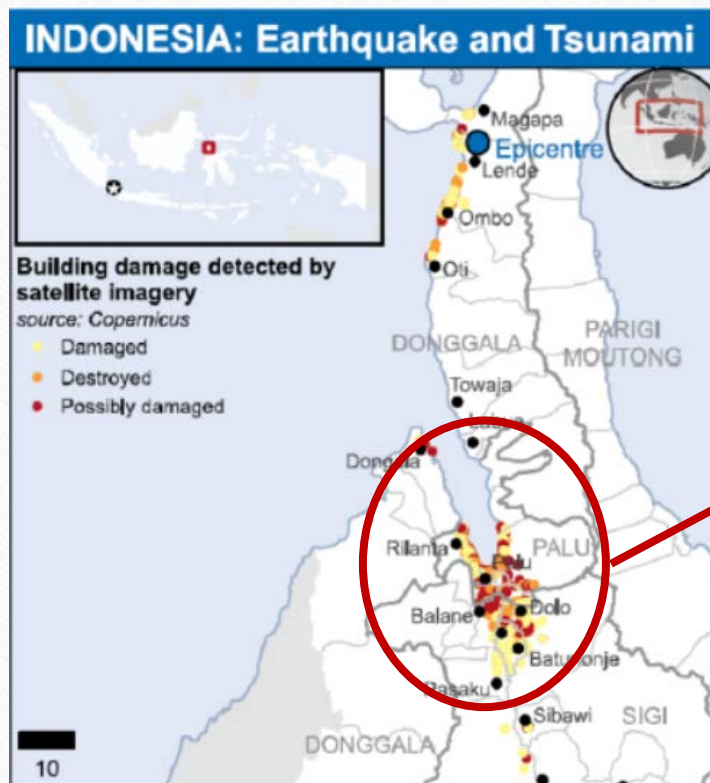


# Case of study: Indonesia (2018)



- ❖ Date: 2018/09/28
- ❖ Start: 10:02 (local hour)
- ❖ Several earthquakes, main with magnitude 7.4
- ❖ 170 aftershocks during the first 48 hours
- ❖ en las primeras 48 hours
- ❖ Tsunami with waves up 10m
- ❖ Soil liquefaction
  
- ❖ 2.000 deceased
- ❖ 5.000 disappeared in the first hours
- ❖ >10.000 seriously injured
- ❖ >70.000 evacuaees

# Case of study: Indonesia (2018) Sulawesi

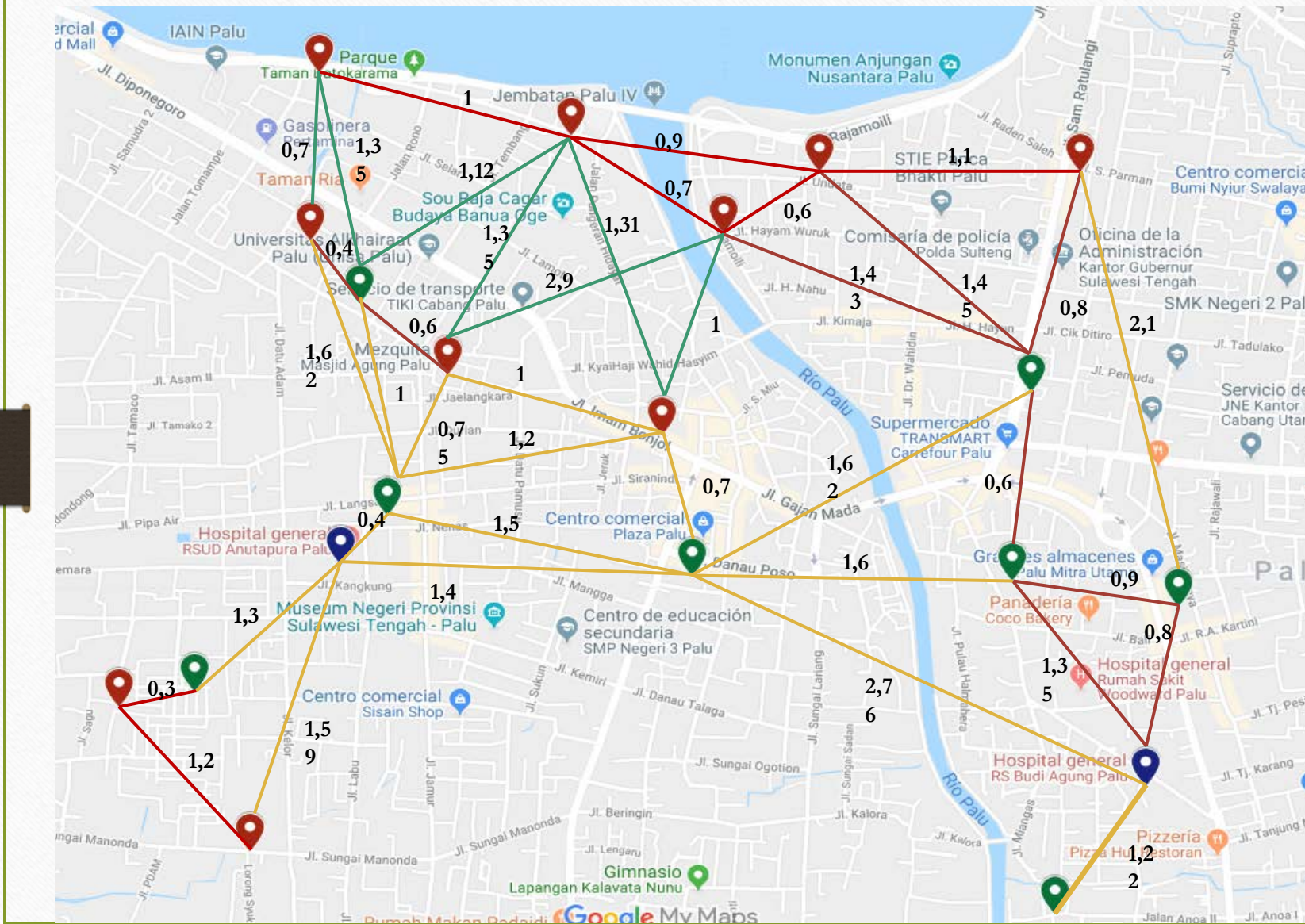


## Damaged infrastructures:

- Roads
- Bridges
- Airport
- Port
- Electric Grid
- Fuel reserves
- Drinking water pipes

## Damaged buildings:

- 700 schools
- 20 medical centres
- 99 religious buildings
- About 66,238 houses (the 99.2% in Palu and surroundings)



### Legend

Road type

Path

Local

Secondary

Primary

Road status

Blocked or shattered

Seriously damaged

Parcialy damaged

Passable

 Affected node

 Hospital

 Temporary shelter

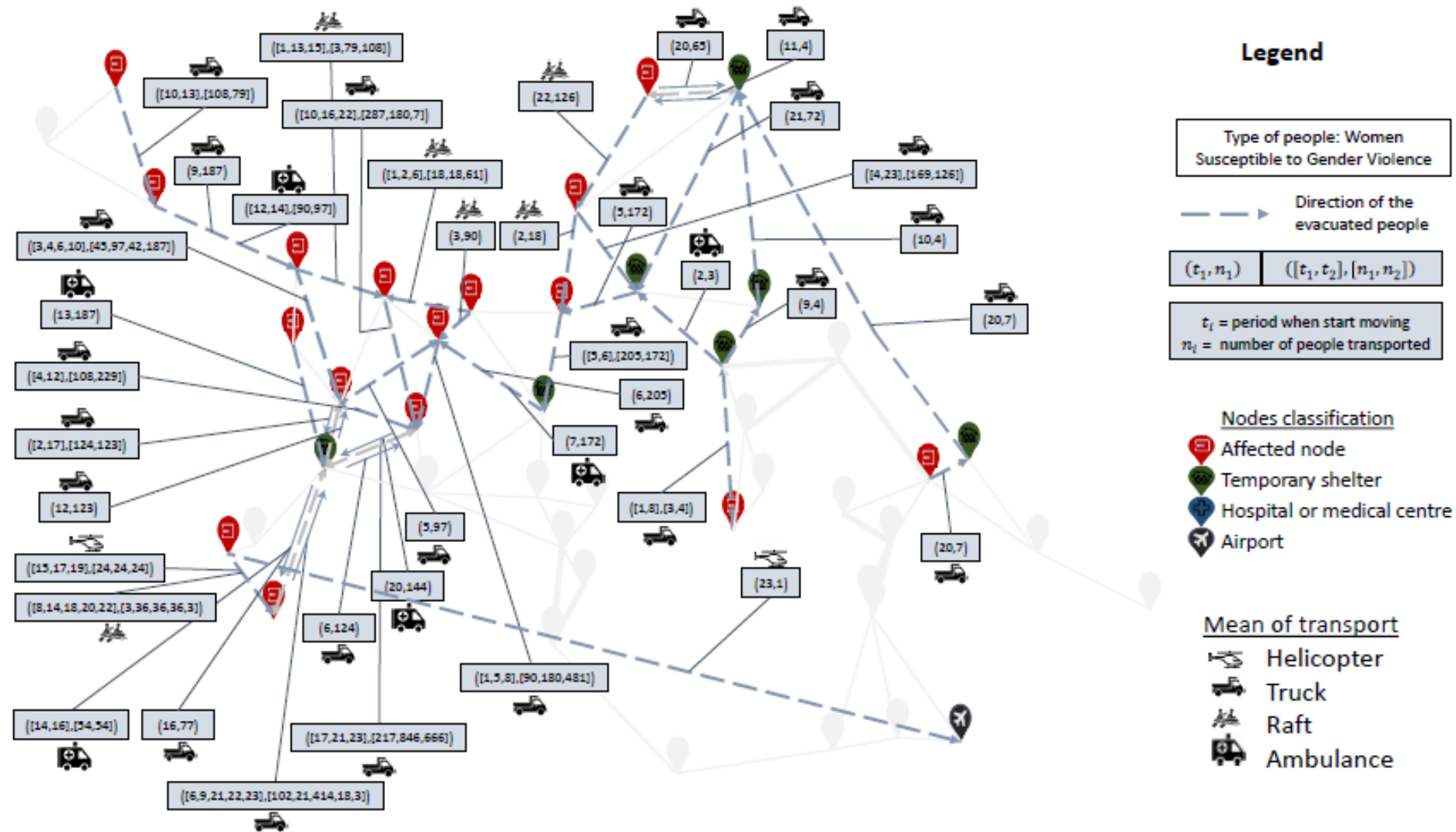
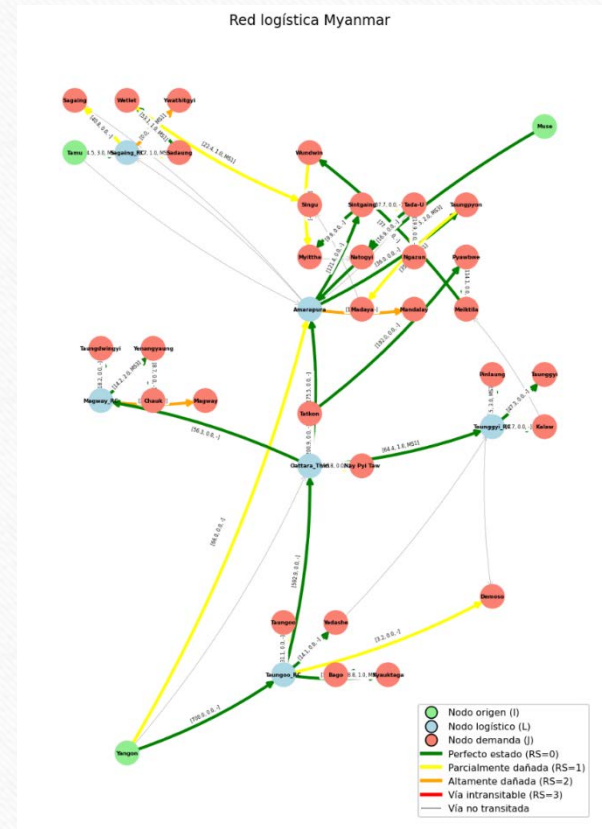
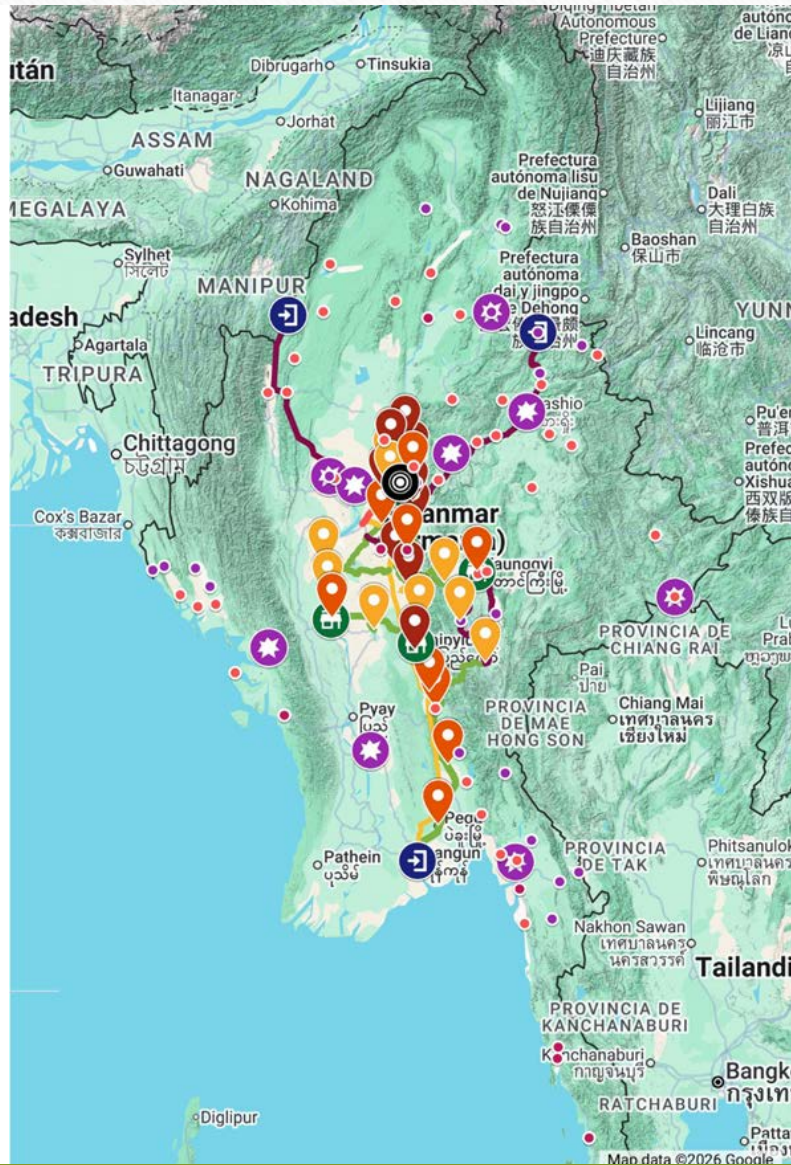
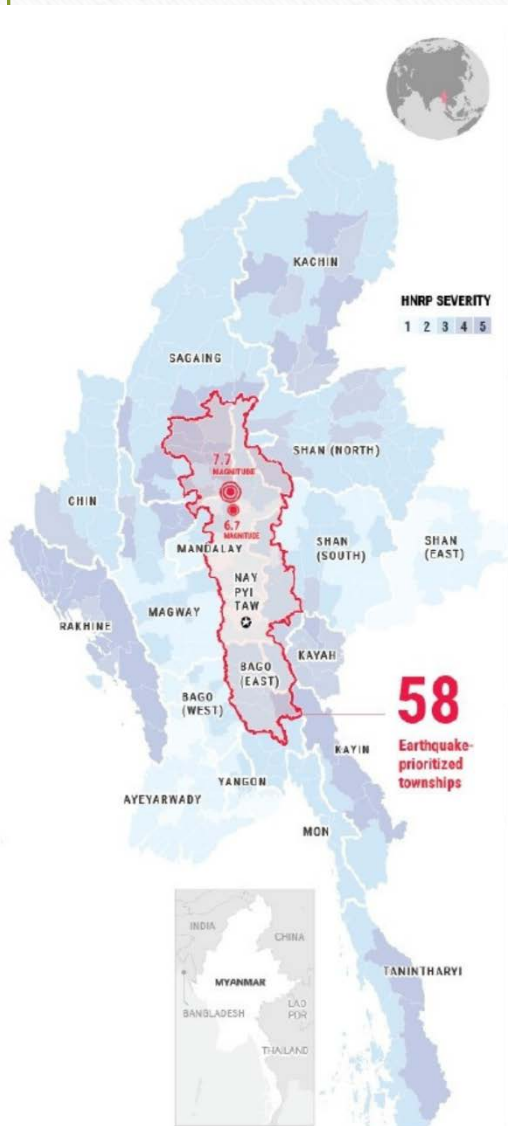


Figure 5. Evacuation of women susceptible to GBV.

# Case of study: Myanmar (2025)



**1** OR for the common Good

**2** Disaster management. Humanitarian Logistics

**3** Some OR Models for HL

**4** Case Studies

**5** Conclusions

Operations  
Research is not  
value-neutral

Every objective  
function encodes  
priorities

Ethical  
responsability  
embedded in  
modeling

Understanding  
key to model

Aligning analytical  
capabilities with  
common good

Humanitarian  
logistics: when  
the objective is  
alliviate  
suffering

