Routing vehicle fleets during disaster relief

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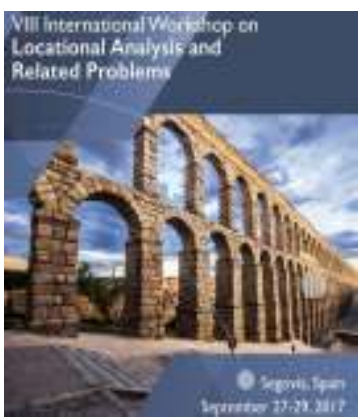


REsearch GROup
on LOCation

Contents

Description of South Sudan (i)

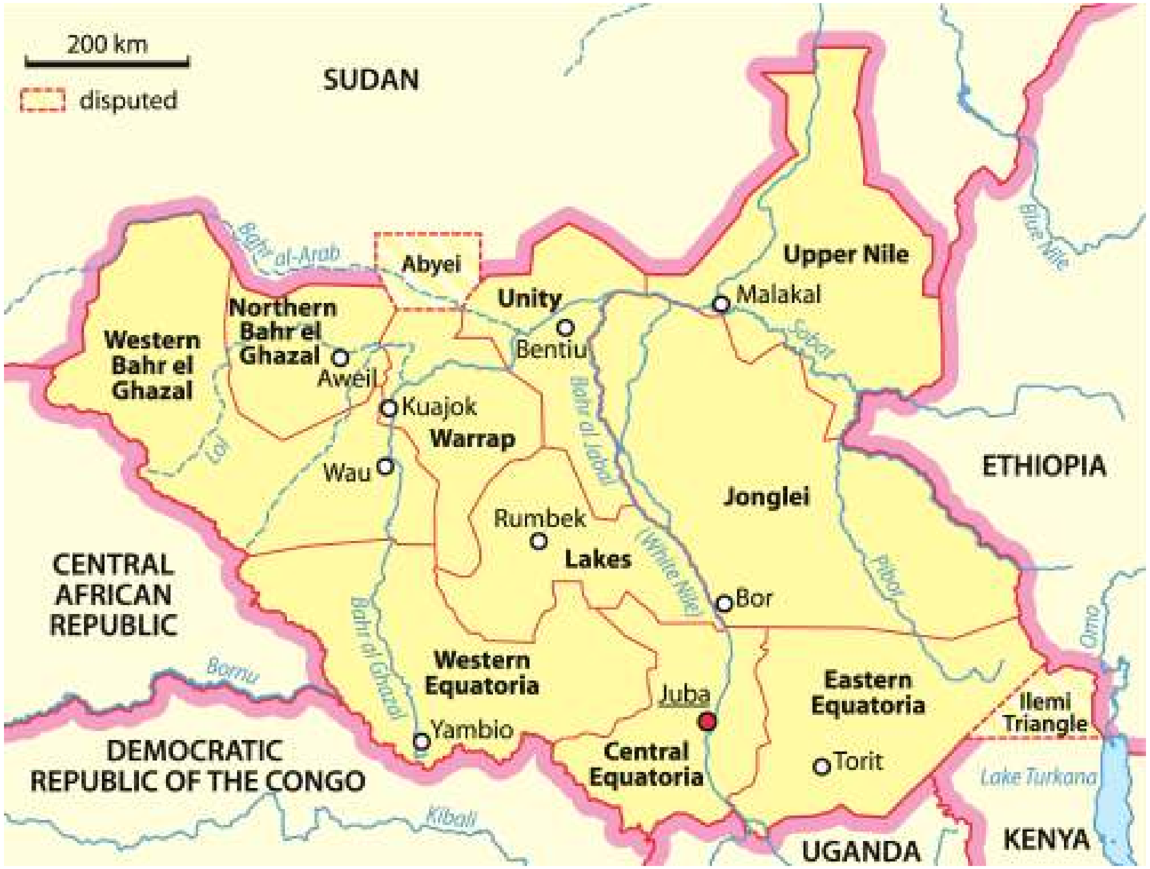
Republic of South Sudan is a country located in the central-eastern part of Africa that achieved its independence from Sudan in 2011.

Its current capital is Juba, with approx. 300.000 inhabitants.

Description of South Sudan (ii)

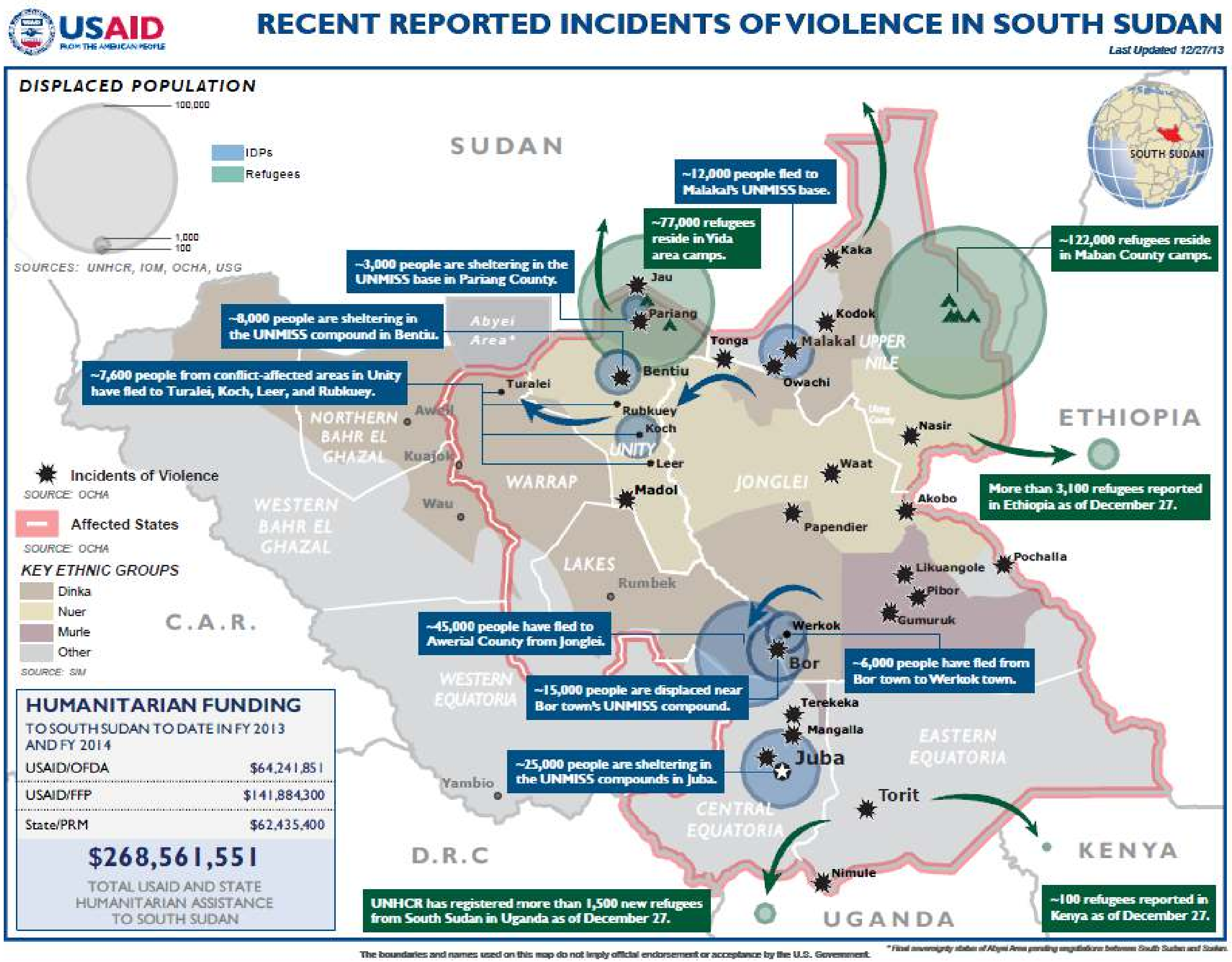
- The country is administratively divided into 10 states, which are further subdivided into 80 counties and 514 smaller administrative units.
- Total South Sudan's population is estimated at 10.6 million inhabitants, with a sparse population density of 15 inhabitants per km^2.
- The 90% of the population lives in rural areas.

(Source: United Nations Development Programme, 2016).

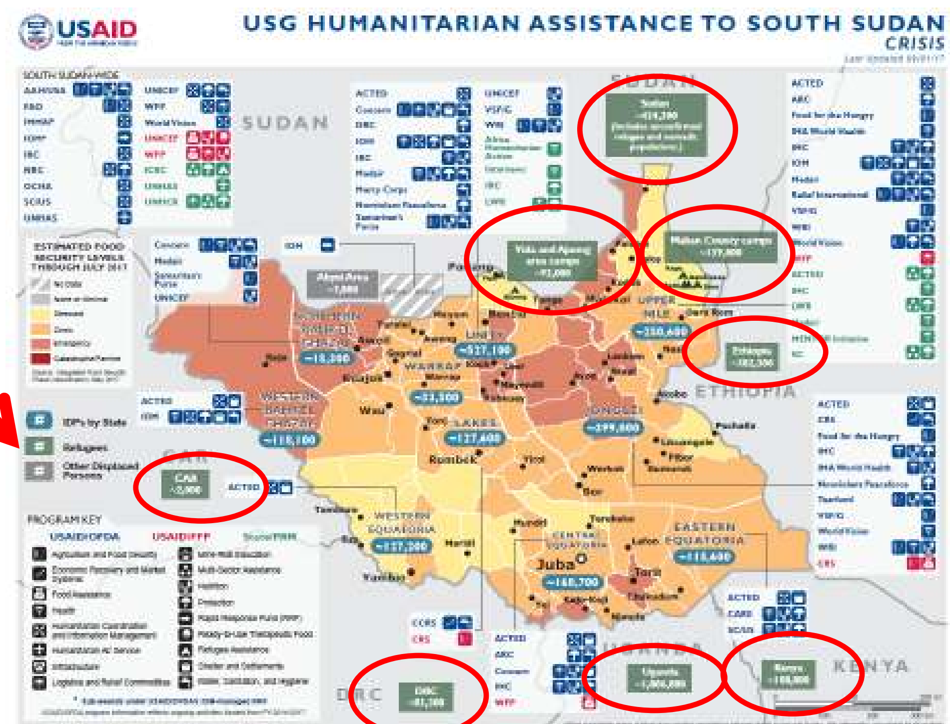


Description of South Sudan (iii)

Intercommunity conflicts and persistent border tensions with the neighboring Sudan have perpetuated the existence of massive movement of returnees and refugees.



Description of South Sudan (iv)

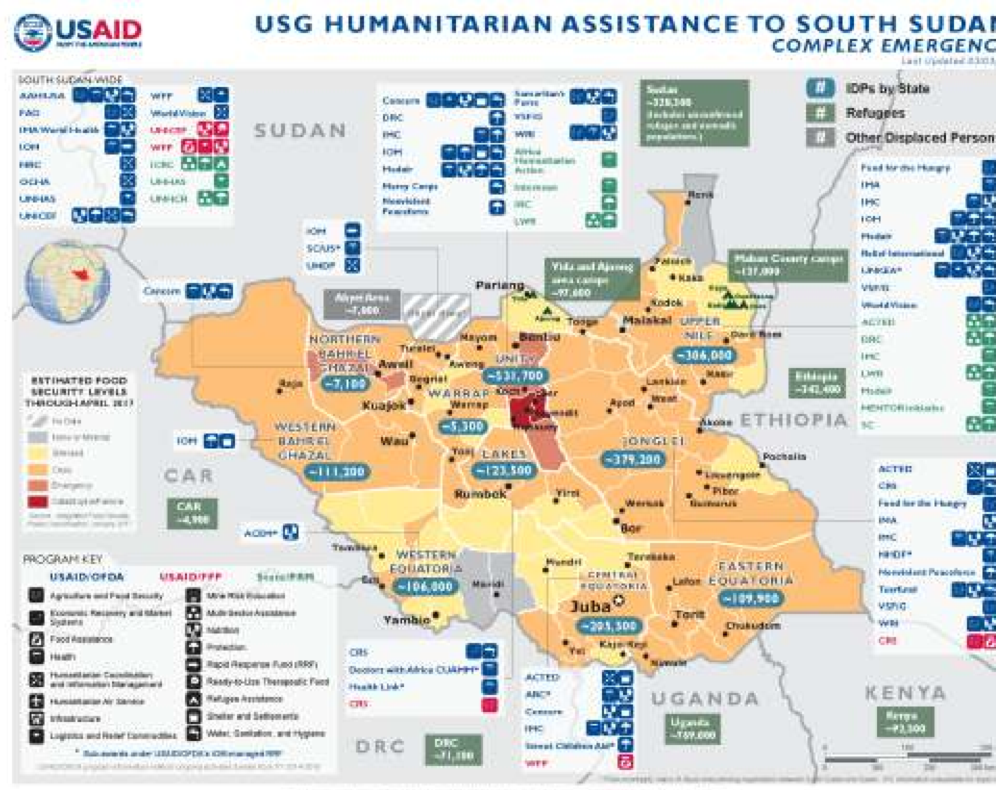


Description of South Sudan (v)

This undesirable situation has also compromised food security and an increasing vulnerability to recurrent outbreaks of communicable diseases.

Description of South Sudan (vii)

In moments of special difficulty for the people, nongovernmental organizations (NGOs) are responsible for almost the 80% of health service delivery.

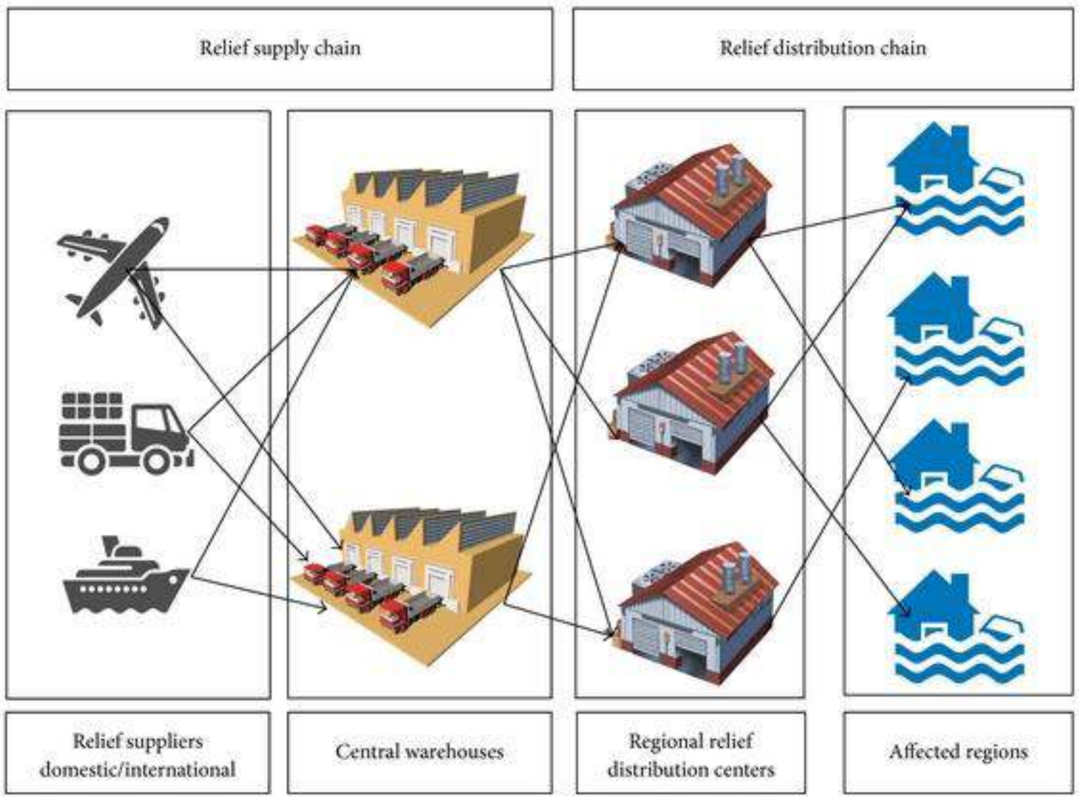


55 NGOs have been working in South Sudan during the last years, and several have been present for more than 30 years.

Humanitarian relief management (i)

Once a disaster occurs, NGOs send logisticians to the disaster areas to assess the type and amount of relief supplies needed. This implies that the Crisis Manager (CM) needs to have previously selected appropriate sites at different network levels, in order to **manage the distribution of goods**.

Within the disaster zone, **Central Warehouses** (CWs) should be located to indirectly supply the points of demands throughout some **local distribution centers** (LDCs), adequately located in the affected zone.



Humanitarian relief management (ii)

Normally, the selection of sites of the LDCs and CWs is done from a set of pre-selected sites that were marked during a preparedness phase.

Humanitarian relief management (iii)

Anaya-Arenas et al. (2014) present a **review with 29 contributions** made in this field, which were classified in accordance to different features, such as data modeling, number of objectives, periods under consideration, commodity types, resolution method, capacity limits, sourcing considerations and the used approaches for allocating resources.

Each LDC site must be selected considering several factors, such as security and safety, transportation infrastructure, and available transportation modes. Based on this information, the CM begins to ship relief supplies to the LDCs.

Humanitarian relief management (iv)

Emergency management can be **divided into different stages**.

As often done in the literature, we decompose the global problem in a succession of subproblems in order to efficiently solve it. **Every phase** of post-disaster response **seeks to minimize the effects of the disaster by helping people as soon as possible** and preventing any more loss, while the recovery phase tries to support the community in order to re-establish their normal state.

There are **four logistical decisions** that commonly influence **last mile relief distribution**. These include:

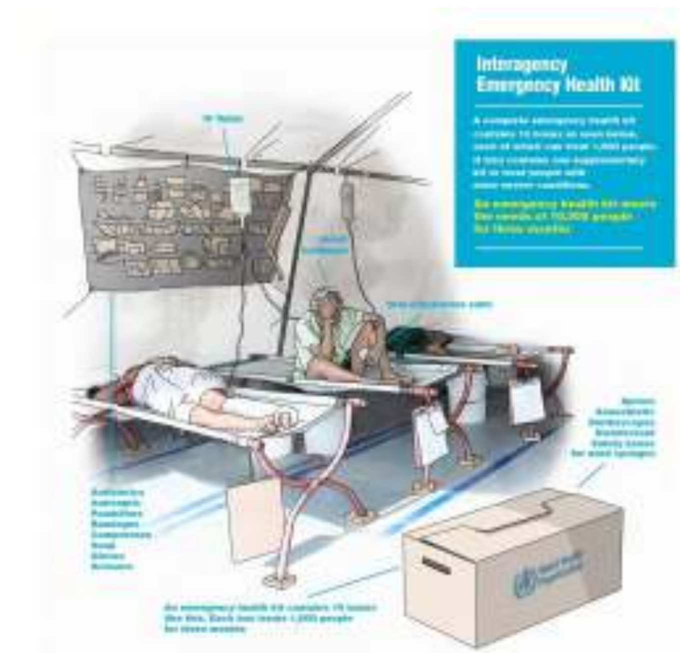
- **facility location**: identifying the most suitable places for inventory in the relief network;
- **inventory management**: efficiently manage the inflow and outflow of the relief materials;
- **transportation decisions**: to transport the relief to the needed area, and
- **distribution decision**: to quickly and efficiently distribute the relief materials to the affected population.

Our modelling approach is decomposed into three phases.

Our modelling approach (i)

Phase I: Locating service centers.

- Take into account the **number of nearby inhabitants** who will arrive by using their own means of transportation, and
- Also the population of close localities who can occasionally be **served** with Type I vehicles (ambulances), through of **circuits that exit and return** from/to the same center.
- A maximum radius of coverage R must be considered.



Our modelling approach (ii)

Phase II: Determination of fleet.

- A complementary **fleet of Type II vehicles** (vans) will be responsible for the **daily transport of medicines** and first aid supplies. The **routes** of those vehicles are already **programmed by the health authorities**, taking into account several factors that and, due to their specificity, it will not be considered in this work.
- Each vehicle typically **departs and returns from a same center** and its cyclical route must be scheduled so that its associated **timetable allows** a timely **return to the starting point**. In this phase the **minimum number of vehicles needed** to cover a series of pre-designed routes would have to be determined.

Our modelling approach (iii)

Phase III: Determination of provisioning circuits.

- Frequently **a massive shipment** (heavy truck) **arrives at one of the service centers**, flooding that facility with sanitary material. This material is not exclusive for the point of reception, and **it is necessary to distribute** this material **towards the rest of service centers as soon as possible** using Type II vehicles.

- To do this, **the initial routes** of the vehicles responsible for daily transport will have to be **partially modified** (for example, by changing the location of their usual depot) so that, **without altering the initially planned visits**, they can help to distribute the supplies received throughout the territory.

A location model for solving Phase I (i)

Our **phase 1** is focused on:

- **Selecting the minimum number of LDC sites** where the different medical teams must be located by using, as candidate sites, the own demanding cities and villages that belong to the affected zone.
- Every demand point should be **served by one or several medical units**; in the second option, the sum of participation percentages of the concerned medical teams should be 1.
- The number of such medical teams and their locations should be determined so that the care at all locations is guaranteed and the cost of deploying medical services in the affected area is minimized.

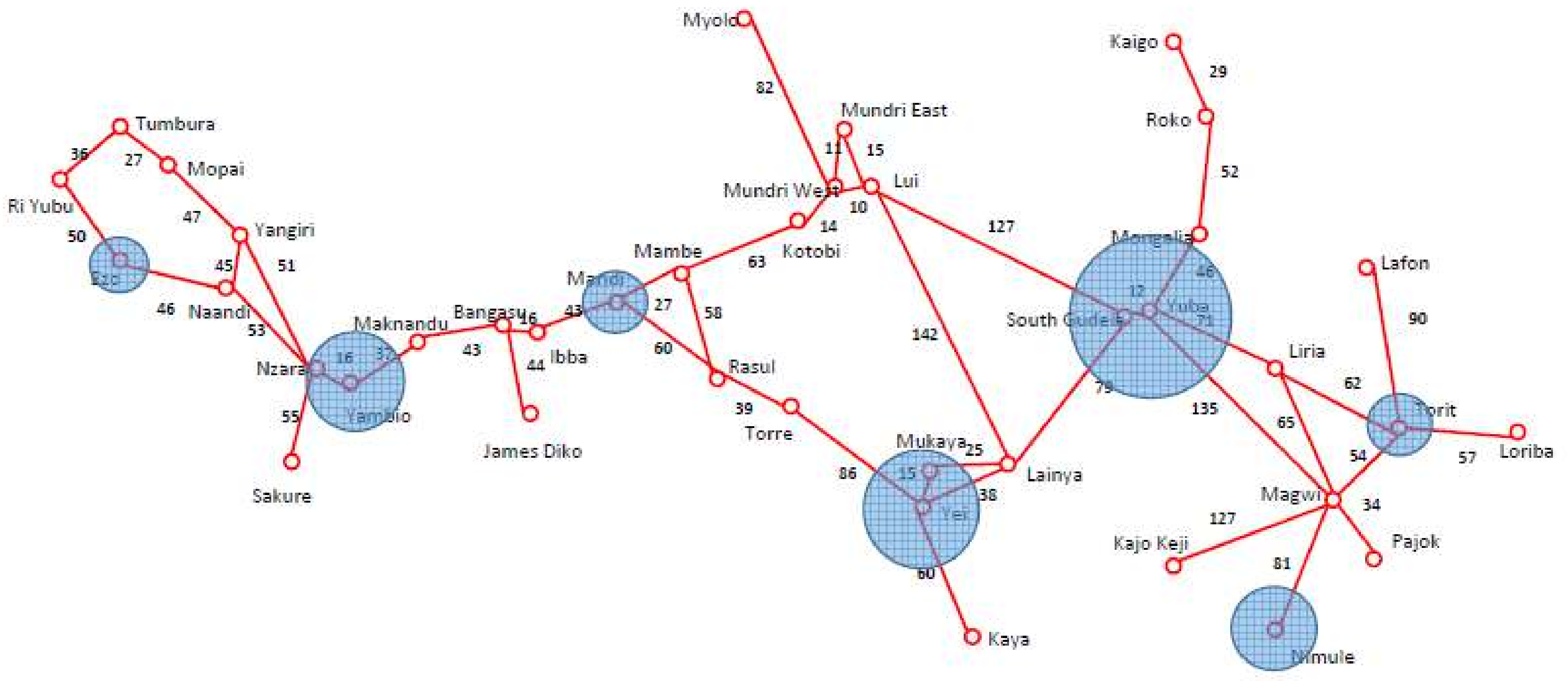
A location model for solving Phase I (ii)

Notation:

$i \in I$: **set of demand points**.
There is a population p_i associated to each demand point.

$j \in J$: **set of candidate LDC sites**. There is a upper bound (cap_j) in terms of capacity associated to each candidate LDC point.

Let us consider an initial directed graph G = (V;A), where V is the set of nodes and A is the arc set. We assume that $J \subset I \subset V$



A location model for solving Phase I (iii)

Assume that the shortest distances between points of set V, along network G, have previously been determined and recorded in the matrix $D = (d_{ij})$.

Let $\mathbf{q_{ij}}$ be a binary expression that takes value 1 if the demand point *i* can be covered by site *j* (i.e., $q_{ij} = 1$ implies $d_{ij}<R$), and value 0, otherwise.

Variables required in the model:

$\mathbf{y_j}$: takes value 1, if location j is activated, and 0, otherwise.

$\mathbf{n_j}$: Number of medical teams to be installed at location j.

$\mathbf{x_{ij}}$: Percentage of care that demand point (village) *i* will receive from location (medical service) *j.*

A location model for solving Phase I (iv)

The objective function **minimizes the number of activated locations** and the **number of medical teams** that should be installed based on the coverage radius and on the capacity restrictions established.

When **radius R decreases**, the number of **medical teams** that can be **concentrated in the same location** will then increase in order to compensate.

$$\text{Min} \sum_{j \in J} c_j y_j + \sum_{j \in J} \beta_j n_j$$

A location model for solving Phase I (v)

Subject to constraints:

$$\sum_{j \in J} q_{ij} y_j \geq k, \quad i \in I \quad (2)$$

Constraints (2) ensure that all villages are covered by at least k locations (usually, k=1).

$$\sum_{j \in J} q_{ij} x_{ij} = 1, \quad i \in I \quad (3)$$

$$x_{ij} \leq y_j, \quad i \in I, \; j \in J \quad (4)$$

$$y_j \leq n_j, \quad j \in J \quad (5)$$

$$\sum_{i \in I} p_i x_{ij} \leq cap_j \, n_j, \quad j \in J \quad (6)$$

$$y_{ij} \in \{0, 1\}; \quad n_j \in Z^+, \quad x_{ij} \in [0, 1] \quad (7)$$

A location model for solving Phase I (vi)

Subject to constraints:

$$\sum_{j \in J} q_{ij} y_j \geq k, \quad i \in I \quad (2)$$

$$\sum_{j \in J} q_{ij} x_{ij} = 1, \quad i \in I \quad (3)$$

Sum of coverage percentages applied to the same village must be 1

$$x_{ij} \leq y_j \,, \quad i \in I,\ j \in J \quad (4)$$

$$y_j \leq n_j \,, \quad j \in J \quad (5)$$

$$\sum_{i \in I} p_i x_{ij} \leq cap_j\, n_j, \quad j \in J \quad (6)$$

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A location model for solving Phase I (vii)

Subject to constraints:

$$\sum_{j \in J} q_{ij} y_j \geq k, \quad i \in I \quad (2)$$

$$\sum_{j \in J} q_{ij} x_{ij} = 1, \quad i \in I \quad (3)$$

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$$\sum_{i \in I} p_i x_{ij} \leq cap_j \, n_j \,, \quad j \in J \quad (6)$$

$$y_{ij} \in \{0,1\}; \quad n_j \in Z^+, \quad x_{ij} \in [0,1] \quad (7)$$

If a location is activated, then at least one medical team must be installed on it

A location model for solving Phase I (viii)

Subject to constraints:

$$\sum_{j \in J} q_{ij} y_j \geq k, \quad i \in I \quad (2)$$

$$\sum_{j \in J} q_{ij} x_{ij} = 1, \quad i \in I \quad (3)$$

$$x_{ij} \leq y_j \,, \quad i \in I, \; j \in J \quad (4)$$

$$y_j \leq n_j \,, \quad j \in J \qquad (5)$$

$$\sum_{i \in I} p_i x_{ij} \leq cap_j \, n_j \,, \quad j \in J \quad (6)$$

$$y_{ij} \in \{0, 1\}; \quad n_j \in Z^+, \quad x_{ij} \in [0, 1] \quad (7)$$

If a location is not activated (yj = 0), then none village can be covered from it.

A location model for solving Phase I (ix)

Subject to constraints:

$$\sum_{j \in J} q_{ij} y_j \geq k, \quad i \in I \quad (2)$$

$$\sum_{j \in J} q_{ij} x_{ij} = 1, \quad i \in I \quad (3)$$

$$x_{ij} \leq y_j \,, \quad i \in I, \ j \in J \quad (4)$$

$$y_j \leq n_j \,, \quad j \in J \quad (5)$$

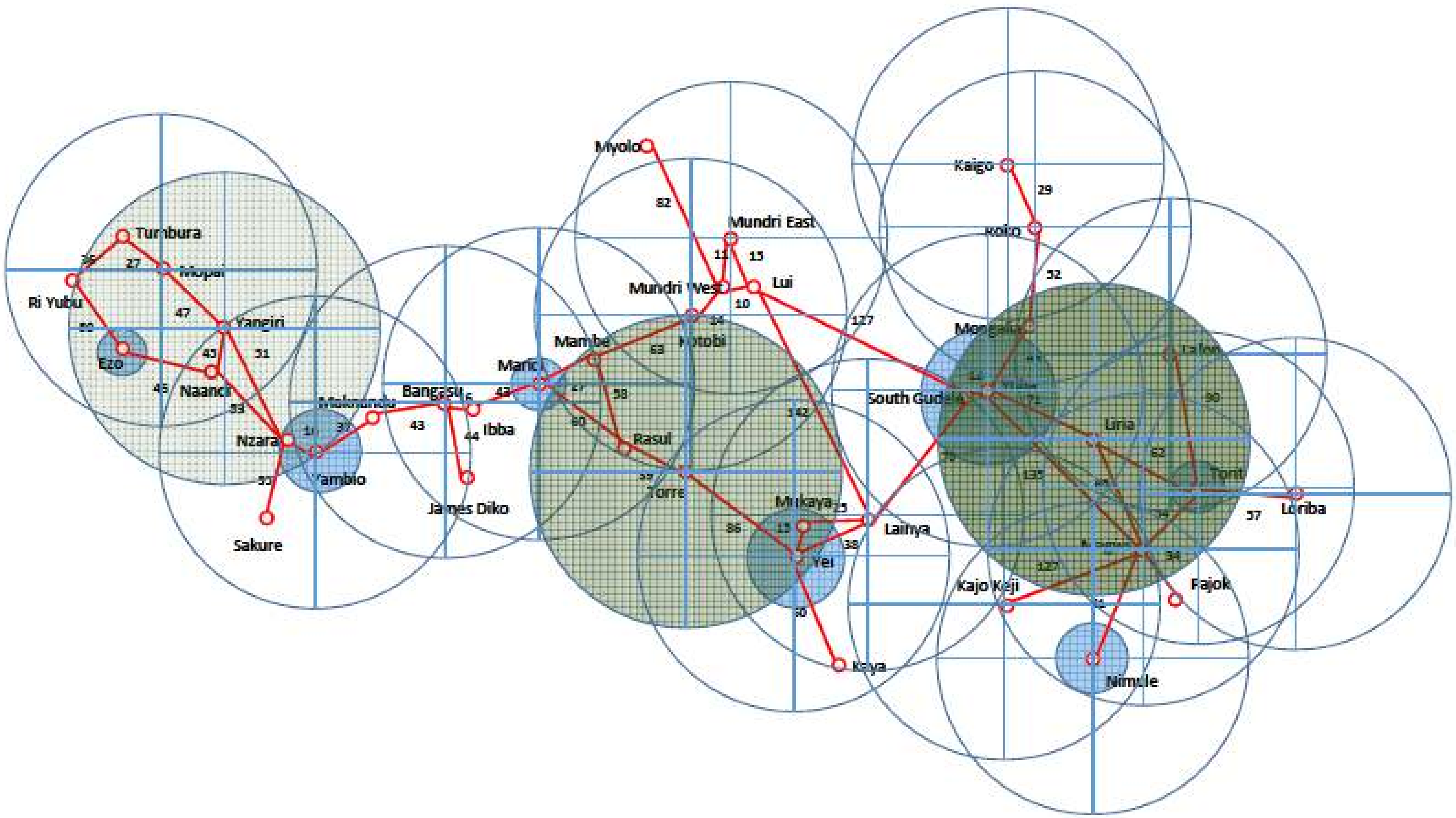
$$\sum_{i \in I} p_i x_{ij} \leq cap_j \, n_j \,, \quad j \in J \quad (6)$$

Service to locate at j can not exceed their capacity

$$y_{ij} \in \{0, 1\}; \quad n_j \in Z^+, \quad x_{ij} \in [0, 1] \quad (7)$$

A location model for solving Phase I (x)

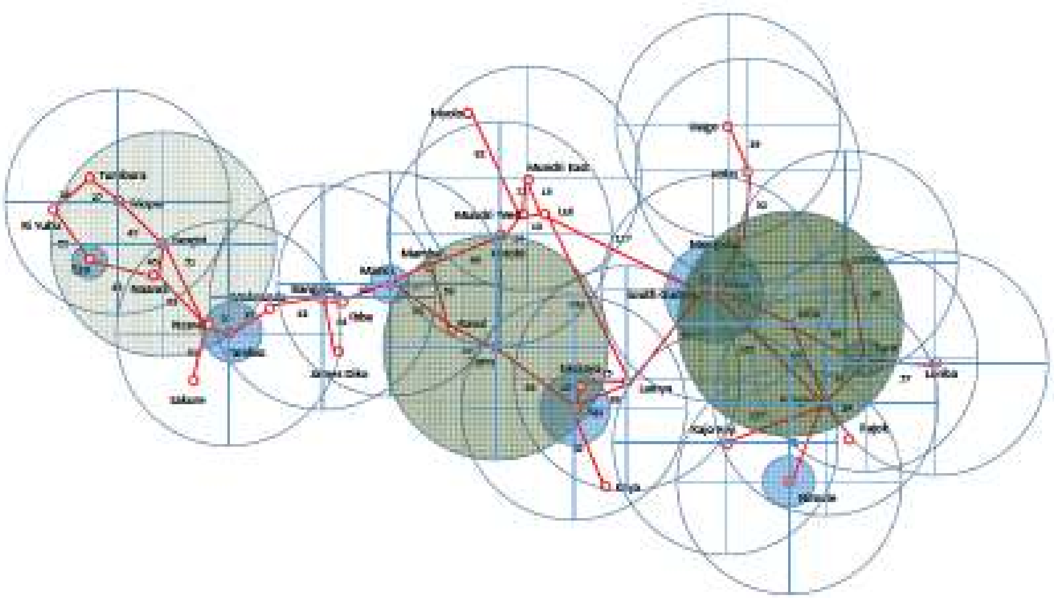
Figure shows the **territorial distribution** of the LDCs.
Big circles of radius R represent the **location and coverage zone of LDC's**.
The **shadow level** of circles are **proportional to the number of medical teams** allocated at each LDC.



A location model for solving Phase I (xi)

Considering a coverage radius R=100 km and a maximum capacity of 5000 users, Table 1 details the distribution of the medical teams at LDCs.

Liria requires the maximum number of medical teams, and that there are several cities which requires only one, mostly due to their proximity to cities with bigger demand.



City	Medical teams
Yanguiri	15
Ezo	8
Kajo Keji	1
Lainya	1
Liria	75
Magwi	8
Mambe	1
Mongalia	1
Mundri West	1
Nzara	2
Rasul	1
South Gudele	1
Torit	6
Torre	36
Total	**158**

A maximum flow problem for solving Phase II (i)

In this Phase, the location of the LDCs is assumed to be already predetermined and its capacity is considered sufficient to serve its service region. Moreover, service zones of LDCs are considered as independent clusters in the relief network, without interaction among resources of different LDCs.

L	set of distribution zones in the territory. Each zone is covered by a route.
T	set of days corresponding to the planning horizon (|*T*|=7, a week)
S_l , E_l	starting and ending CW sites of distribution zone l, which have been previously fixed at the end of Phase I.
V_{lt}	set of services in each distribution zone for each day.

Each transport service $\mathrm{i} \in \mathrm{V}_{\mathrm{lt}}$ is **defined by its origin and destination nodes** (noted by $\mathrm{o}_{\mathrm{lt}}^{\mathrm{i}}$ and $\mathrm{d}_{\mathrm{lt}}^{\mathrm{i}}$, respectively) in an **event-activity graph** similar to the one proposed in EWGLA -2016.

Nodes contain information regarding the starting and ending LDCs along the distribution zone as well as by the departure and arrival times at those points.

A maximum flow problem for solving Phase II (ii)

Hence, the *i-th* service of the distribution zone *l* for the day *t* can completely be specified **by using operators s(.) and T(.)**, such that the following four elements can be determined:

$s(S_{lt})$: depot location where route for distribution zone l starts.
$s(E_{lt})$: depot location where route for distribution zone l ends.
$T(S_{lt})$: fictitious departure time from the depot of vehicles that provides service in distribution zone l during day t.
$T(E_{lt})$: fictitious arrival time to the depot of vehicles that provide service in distribution zone l during day t.

Node set N_{lt} contains all possible events relative to the distribution zone l during day t:

$$N_{lt} = \{o_{lt}^{i}, d_{lt}^{i}; \forall i \in V_{lt}\} \cup \{S_{lt}, E_{lt}\}$$

Finally, set N represents all nodes that will be used in the model:

$$N = \bigcup_{l \in L, t \in T} N_{lt}$$

A maximum flow problem for solving Phase II (iii)

Since the itinerary is considered mandatory, **it is enough to identify the nodes associated with the beginning and the end of the activity** to determine the complete service .
At the **beginning of the day**, each vehicle must start the daily route from the respective depot by visiting the one of the LDCs acting as origin of services. These displacements are represented by the following subsets of arcs:

$$A_{lt}^{S} = \left\{ (S_{lt}, o_{lt}^{i}); \forall i \in V_{lt} \right\}; \quad l \in L, t \in T$$

Sets of arcs that represent the **operative services**:

$$A_{lt} = \left\{ (o_{lt}^{i}, d_{lt}^{i}); \forall i \in V_{lt} \right\}; \quad l \in L, t \in T$$

When a vehicle completes one service, it has several options. One possibility consists of **connecting to another activity** within the **same** distribution zone and on the **same** day

$$A_{lt}^{+} = \left\{ (d_{lt}^{i}, o_{lt}^{j}); \forall i, j \in V_{lt}, i \neq j : T\left(d_{lt}^{i}\right) + \tau_{ij} \leq T\left(o_{lt}^{j}\right) \right\}; \quad l \in L, t \in T$$

A maximum flow problem for solving Phase II (iv)

In order to **move** the vehicle **toward the rest facility** of the **same** distribution zone, the following sets of arcs should be added:

$$A_{lt}^{E} = \left\{ (d_{lt}^{i}, E_{lt}); \forall i \in V_{lt} \right\}; \quad l \in L, t \in T$$

If the vehicle is moved toward the rest facility of **another distribution zone** to reinforce the service of that other distribution zone at the next day,

$$A_{L\setminus\{l\}t}^{E} = \left\{ (d_{lt}^{i}, E_{l't}); i \in V_{lt}, l' \in L \setminus \{l\} \right\}; \quad l \in L, t \in T$$

Analogously, the following arc sets, **connecting the end of a day to** start **activities at the next days**

$$A_{lt^+}^{ES} = \left\{ (E_{lt}, S_{lt'}); \forall t < t' \leq H \right\}; \quad l \in L, t \in T$$

$$A_{L\setminus\{l\}t^+}^{ES} = \left\{ (E_{lt}, S_{l't'}); \forall t < t' \leq H, \quad l' \in L \setminus \{l\} \right\}; \quad l \in L, t \in T$$

Finally, set A contains all arcs that will be used in the model:

$$A = \bigcup_{l \in L, t \in T} \left(A_{lt}^{S} \cup A_{lt} \cup A_{lt}^{+} \cup A_{lt}^{E} \cup A_{L\setminus\{l\}t}^{E} \cup A_{lt^+}^{ES} \cup A_{L\setminus\{l\}t^+}^{ES} \right)$$

Model for computing the minimum required fleet (i)

Let x_{ij} be the flow on arc $(i, j) \in A$

Let $P(i) = \{ j \in N : \quad (j, i) \in A \}$ be the set predecessor nodes of node i.

and let $S(i) = \{ j \in N : \quad (i, j) \in A \}$ be the successor nodes of node i.

Consider the binary variable $\varphi_j \in \{0,1\}$ which takes value 1 if depot *s(j)* is activated, where $s(j) \in \{ S_l \cup E_l : l \in L \}$

In this phase we compute the number of vehicles needed at each distribution zone and day NV_{lt} by **minimizing the number of shipments required to perform the scheduling at every distribution zone and every day**:

$$\mathrm{Min}\ NV_{lt} := \sum_{i \in V_{lt}} x_{S_{lt}\, o_{lt}^{i}}$$

Model for computing the minimum required fleet (ii)

Subject to constraints:

$$\sum_{j \in S(i)} x_{ij} - \sum_{k \in P(i)} x_{ki} = 0, \quad i \in N \qquad (9)$$

Flow conservation for each vehicle at every node in the event-activity graph

$$x_{ij} = 1, \quad (i, j) \in A_{lt}, l \in L, t \in T \qquad (10)$$

$$x_{ij} \leq C_j, \quad i \in P(j), j \in E_{lt}, l \in L, t \in T \qquad (11)$$

$$x_{ij} \geq 0, \quad (i, j) \in A \qquad (12)$$

Model for computing the minimum required fleet (iii)

Subject to constraints:

$$\sum_{j \in S(i)} x_{ij} - \sum_{k \in P(i)} x_{ki} = 0, \quad i \in N \quad (9)$$

$$x_{ij} = 1, \quad (i, j) \in A_{lt}, l \in L, t \in T \quad (10)$$

All scheduled services are performed by only one vehicle

$$x_{ij} \leq C_j, \quad i \in P(j), j \in E_{lt}, l \in L, t \in T \quad (11)$$

$$x_{ij} \geq 0, \quad (i, j) \in A \quad (12)$$

Model for computing the minimum required fleet (iv)

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$$x_{ij} \geq 0, \quad (i, j) \in A \qquad (12)$$

Forbidding ingoing flow to origin nodes without activated rest facilities and Including a limitation according to the depot capacity

Model for computing the minimum required fleet (v)

The previous model describes a procedure to compute the minimum number NV_{lt}^{*} for each distribution zone and day of required vehicles, in order to accomplish the set of services V_{lt}

Therefore, we can use the following expression **to obtain the total fleet size** for the whole planning horizon:

$$NV^{*} = \max_{t \in T} \left\{ \sum_{l \in L} NV_{lt}^{*} \right\}$$

A MIP model for determining the circulation plan (i)

In the third phase, we assume that the location of LDC points has already been fixed and we use the previous information to design the most convenient routes (for each distribution zone and day) and the circulations (for the whole planning horizon) by means of a MIP model, while the lengths of routes are balanced.

Let **K be the required set of vehicles**, whose cardinality is NV^*.

Now, let $\mathrm{x}_{\mathrm{ij}}^{\mathrm{k}}$ be a binary variable that takes value 1 if vehicle $\mathrm{k} \in \mathrm{K}$ circulates along the arc *(i,j)*.

Assuming that expression d_{ij} represent the length of arc *(i,j)*, the following model **minimizes the total number of kilometers** performed by the fleet, and additionally **equilibrates the mileages covered by each unit**.

$$\min \quad \sum_{(i,j)\in A} \sum_{k\in K} \hat{c}_{ij}\, d_{ij}\, x_{ij}^k + \tilde{c}\, M\, z$$

A MIP model for determining the circulation plan (ii)

$$\min \sum_{(i,j)\in A} \sum_{k\in K} \hat{c}_{ij}\, d_{ij}\, x_{ij}^{k} + \tilde{c}\, M\, z$$

The objective function is composed of two terms.

- The first term minimizes the cost due to the total number of kilometers traveled by all vehicles during the planning horizon T .
- The second one aims at balancing the distance traveled by each vehicle during T.

- COSTS:

$\hat{c}_{ij}$ is the cost of running a vehicle per unit of distance

$\tilde{c}$ is an average cost per unit of distance

A MIP model for determining the circulation plan (iii)

Subject to constraints:

$$\sum_{j \in \mathcal{S}(i)} x_{ij}^k - \sum_{r \in \mathcal{P}(i)} x_{ri}^k = 0, \quad i \in N,\ k \in \mathcal{K}$$

$$\sum_{k \in \mathcal{K}} x_{ij}^k = 1, \quad (i,j) \in A_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$\sum_{k \in \mathcal{K}} x_{ij}^k = I_j, i \in P(j),\ j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$I_j \le C_j, i \in P(j),\ j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$I_j = I_{l0},\ l \in \mathcal{L}:\ j \in E_{lH}$$

$$\sum_{(i,j) \in A} d_{ij}\ x_{ij}^k \le z, \quad k \in \mathcal{K}$$

$$x_{ij}^k \in \{0,1\}, \quad (i,j) \in A,\ k \in \mathcal{K}$$

$$I_j \ge 0,\ j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$z \ge 0.$$

Flow conservation for each vehicle at every node in the event-activity graph

A MIP model for determining the circulation plan (iii)

Subject to constraints:

$$\sum_{j \in \mathcal{S}(i)} x_{ij}^k - \sum_{r \in \mathcal{P}(i)} x_{ri}^k = 0, \quad i \in N,\ k \in \mathcal{K}$$

$$\sum_{k \in \mathcal{K}} x_{ij}^k = 1, \quad (i,j) \in A_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

All services are performed by only one vehicle

$$\sum_{k \in \mathcal{K}} x_{ij}^k = I_j, i \in P(j),\ j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$I_j \leq C_j, i \in P(j),\ j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$I_j = I_{l0},\ l \in \mathcal{L} :\ j \in E_{lH}$$

$$\sum_{(i,j) \in A} d_{ij}\, x_{ij}^k \leq z, \quad k \in \mathcal{K}$$

$$x_{ij}^k \in \{0,1\}, \quad (i,j) \in A,\ k \in \mathcal{K}$$

$$I_j \geq 0,\ j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$z \geq 0.$$

A MIP model for determining the circulation plan (iii)

Subject to constraints:

Define the inventory of vehicles at each depot and day

$$\sum_{j\in\mathcal{S}(i)} x_{ij}^k - \sum_{r\in\mathcal{P}(i)} x_{ri}^k = 0, \quad i\in N,\ k\in\mathcal{K}$$

$$\sum_{k\in\mathcal{K}} x_{ij}^k = 1, \quad (i,j)\in A_{lt},\ l\in\mathcal{L},\ t\in\mathcal{T}$$

$$\sum_{k\in\mathcal{K}} x_{ij}^k = I_j, i\in P(j),\ j\in E_{lt},\ l\in\mathcal{L},\ t\in\mathcal{T}$$

$$I_j \le C_j, i\in P(j),\ j\in E_{lt},\ l\in\mathcal{L},\ t\in\mathcal{T}$$

$$I_j = I_{l0},\ l\in\mathcal{L}:\ j\in E_{lH}$$

$$\sum_{(i,j)\in A} d_{ij}\, x_{ij}^k \le z, \quad k\in\mathcal{K}$$

$$x_{ij}^k \in \{0,1\}, \quad (i,j)\in A,\ k\in\mathcal{K}$$

$$I_j \ge 0, j\in E_{lt},\ l\in\mathcal{L},\ t\in\mathcal{T}$$

$$z \ge 0.$$

A MIP model for determining the circulation plan (iii)

Subject to constraints:

$$\sum_{j \in \mathcal{S}(i)} x_{ij}^k - \sum_{r \in \mathcal{P}(i)} x_{ri}^k = 0, \quad i \in N,\ k \in \mathcal{K}$$

$$\sum_{k \in \mathcal{K}} x_{ij}^k = 1, \quad (i,j) \in A_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$\sum_{k \in \mathcal{K}} x_{ij}^k = I_j, i \in P(j),\ j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$I_j \leq C_j, i \in P(j),\ j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$I_j = I_{l0},\ l \in \mathcal{L}:\ j \in E_{lH}$$

$$\sum_{(i,j) \in A} d_{ij}\, x_{ij}^k \leq z, \quad k \in \mathcal{K}$$

$$x_{ij}^k \in \{0,1\}, \quad (i,j) \in A,\ k \in \mathcal{K}$$

$$I_j \geq 0, j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$z \geq 0.$$

Ensure that the number of vehicles satisfy capacity constraints at depot locations

A MIP model for determining the circulation plan (iii)

Subject to constraints:

$$\sum_{j \in \mathcal{S}(i)} x_{ij}^k - \sum_{r \in \mathcal{P}(i)} x_{ri}^k = 0, \quad i \in N,\ k \in \mathcal{K}$$

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$$z \geq 0.$$

Initial number of vehicles at depot of distribution zone *l*

A MIP model for determining the circulation plan (iii)

Subject to constraints:

$$\sum_{j \in \mathcal{S}(i)} x_{ij}^k - \sum_{r \in \mathcal{P}(i)} x_{ri}^k = 0, \quad i \in N,\ k \in \mathcal{K}$$

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$$I_j \geq 0,\ j \in E_{lt},\ l \in \mathcal{L},\ t \in \mathcal{T}$$

$$z \geq 0.$$

Equilibrate the number of kilometers traveled by each vehicle along the planning horizon T

CONCLUSIONS

- A modelling approach for humanitarian logistic management, applied to the actual situation in Republic of South Sudan, has been presented.

- Our approach consists of a three phase methodology:

- First, we propose a model to locate service centers that receive goods to be distributed among other sites, scattered over the affected territory, that need those goods.

- Next, in order to design the routes for vehicles for delivering them,
    - the minimum fleet size required to perform all services is determined; and finally,
    - a model to identify the optimal routes for the emergency services is proposed, where additionally the total number of kilometers traveled by each vehicle is equilibrated.

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Thanks for your attention !

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