Locating Temporary Shelter Areas after a Large-Scale Disaster

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Disasters in Turkey

Type of Disaster	# of households destroyed	Percentage (%)
Earthquake	495.000	79
Landslide	63.000	10
Flood	61.000	9
Rock Fall	26.500	4
Avalanche	5.154	1
	650.654	100

Source: Ozmen et al. (2005)

Shelter Areas

After a disaster, homeless people stay in shelter areas.

- Sphere Project:
  - Started in 1997 by several humanitarian organizations and IFRC
  - Defines standards and some quality measurements for humanitarian operations.

Shelter Areas

After a disaster, homeless people stay in shelter areas.

- For temporary settlements,
  - Must plan settlement areas, access to those areas and routes to public facilities. These areas should be far from threat zones.
  - Must provide enough supply of tents, shelter kits, construction kits and cash.
  - Must provide adequate space to everyone to live
  - Must provide necessary utilities to achieve best thermal conditions.

Turkish Red Crescent

- In Turkey, TRC is the main authority for identifying the shelter area locations.
  - First they identify the candidate locations.
  - Each candidate location has a weight w.r.t. some criteria
  - Sort w.r.t. these weights and open facilities one by one until there is enough space for all the population.

Turkish Red Crescent

- Criteria:
  - Transportation of relief items
  - Procurement of relief items
  - Healthcare institutions
  - Structure and type of the terrain
  - Slope of the terrain
  - Flora of the terrain
  - Electrical infrastructure
  - Sewage infrastructure
  - Permission to use

Turkish Red Crescent

- No population – shelter area assignment
- No consideration of shelter area utilization
- Distances between population and shelter area is ignored

Problem Definition

- Develop a methodology that decides on
  - the locations of the shelter areas
  - assignment of population points to shelter areas
  - considers utilization of shelter areas
  - considers distances between shelter areas and the affected population.

Mathematical Model

TRC Criteria:

- Transportation of relief items
- Procurement of relief items
- Healthcare institutions
- Structure and type of the terrain
- Slope of the terrain
- Flora of the terrain
- Electrical infrastructure
- Sewage infrastructure
- Permission to use

Weight function

Data created using GIS

Mathematical Model

- Maximize the *minimum weight of operating shelters.*
- Accessibility:
  - Minimize *total distance from the shelter areas to nearest main roads and health facilities.*
- Efficiency:
  - Maximize the *total utilization of open shelter areas.*
- Balance:
  - Minimize the *maximum pairwise utilization difference of open shelter areas.*

Mathematical Model

- Subject to;
  - Assign each district (population point) to an area (shelter)
  - Respect capacity of shelter areas
  - Calculate utilization

Mathematical Model

The population needs to be converted into “demand”

$$demand_j = population_j \times percentAffected \times livingSpace$$

- *percentAffected*: percentage of population that is assumed to live in the shelter areas
- *livingSpace*: assigned living space per person
- $population_j$: the number of people living in district j

Mathematical Model

Sets

- I: set of candidate locations
- J: set of districts

Mathematical Model

Parameters

w_i : weight of candidate location *i*, between 0 and 1.

d_i^{health} : distance b/w candidate location *i* and nearest health bldg.

d_i^{road} : distance between candidate location *i* and nearest main road

$demand_j$: total demand of the area *j* (in m^2)

cap_i : capacity of candidate location *i* (in m^2)

$dist_{ij}$: distance between candidate location *i* and demand point *j*

utilSpace: assigned space for utilities per shelter area

Mathematical Model

- **Decision Variables**

$$x_i : \begin{cases} 1, if\ candidate\ location\ i\ is\ chosen \\ 0, \qquad\qquad\qquad\qquad otherwise \end{cases}$$

$$y_{ij} : \begin{cases} 1, if\ district\ j\ is\ assigned\ to\ location\ i \\ 0, \qquad\qquad\qquad\qquad otherwise \end{cases}$$

u_i : Utilization of the candidate location i.

Mathematical Model

Constraints (Capacity and Assignment)

- Assign every district to a shelter area

$$\sum_{i \in I} y_{ij} = 1 \quad \forall\, j \in J$$

Constraints (Capacity and Assignment)

- Capacity constraints of shelter areas

$$\sum_{j \in J} y_{ij} * Demand_j + utilSpace * x_i \leq cap_i * x_i$$

$$\forall i \in I$$

Constraints (Utilization)

- Calculate the utilization of each shelter area,

$$u_i = \frac{\sum_{j \in J} y_{ij} * Demand_j}{Cap_i} \qquad \forall\, i \in I$$

Objective Functions

- Maximize the minimum weight of operating areas.

Maximize

$$\left(\min\left(w_i * x_i + (1 - x_i) \mid i \in I\right)\right) \quad \textbf{(O1)}$$

Objective Functions

- Minimize total distance from the shelter areas to nearest main roads and health facilities.

- $\boldsymbol{minimize} \sum_{i \in I} d^{i}_{health} * x_i$ **(O2)**
- $\boldsymbol{minimize} \sum_{i \in I} d^{i}_{road} * x_i$ **(O3)**

Objective Functions

- Maximize the total utilization of open shelter areas.

$$\boldsymbol{maximize} \sum_{i \in I} \boldsymbol{u_i} \qquad \textbf{(O4)}$$

Objective Functions

- Minimize the total pair wise utilization difference of open shelter areas.

$$\boldsymbol{minimize} \sum_{i \in I} \sum_{\substack{k \in I \\ k < i}} |u_i - u_k| * x_i * x_k$$

(O5)

Objective Functions

- Minimize the total distance

$$\boldsymbol{minimize} \sum_{i \in I} \sum_{j \in J} \boldsymbol{dist_{ij}} * \boldsymbol{x_{ij}} \qquad \textbf{(O6)}$$

Selecting the Best Objective

- Select one objective function for the model
- Introduce other five objectives as constraints
- Choose O1 as primary objective

(O2) and (O3)

- Minimize total distance from the shelter areas to nearest main roads and health facilities.
- Define new parameters
  - *DistHealth* : max allowed shelter area - health institutions distance
  - *DistRoad* : max allowed shelter area - mainroad distance
- Add Constraints:

$$d_i^{health} * x_i \leq \text{DistHealth} \quad \forall\, i \in I$$

$$d_i^{road} * x_i \leq \text{DistRoad} \quad \forall\, i \in I$$

(O4)

- Maximize the total utilization of open shelter areas.
- Define a threshold value, and force utilization to be greater than it.
- β : Threshold value for minimum utilization of open shelter areas
- Add constraint:

$$u_i \geq \beta * x_i \quad i \in I$$

(O5)

- Minimize the total pair wise utilization difference of open shelter areas.
- Define a threshold value similarly
- α : Threshold value for pair wise utilization difference of candidate shelter areas
- Add constraint:

$$\left| u_i - u_j \right| * x_i * x_j \leq \alpha \quad \forall\, i, j \in I$$

(O5)

$$\left|u_i - u_j\right| * x_i * x_j \leq \alpha \quad \forall\, i \in I, j \in I$$

- How to linearize?

1. Multiplication of many variables
2. Absolute value linearization

(O5)

$$\left|u_i - u_j\right| * x_i * x_j \leq \alpha \quad \forall\, i \in I, j \in I$$

- How to linearize?

1. Multiplication of many variables

If $x_i = 1$ and $x_j = 1 \Rightarrow \left|u_i - u_j\right| \leq \alpha$

(O5)

$$\left|u_i - u_j\right| * x_i * x_j \leq \alpha \quad \forall\, i \in I, j \in I$$

- How to linearize?

1. Multiplication of many variables

If $x_i = 1$ and $x_j = 1 \Longrightarrow \left|u_i - u_j\right| \leq \alpha$

$$|u_i - u_j| \leq \alpha + (1 - x_i) + (1 - x_j)\ \forall\, i, j \in I$$

(O5)

$$\left|u_i - u_j\right| * x_i * x_j \leq \alpha \quad \forall\, i \in I, j \in I$$

- How to linearize?

2. Absolute value linearization

$$u_i - u_j \leq \alpha + (1 - x_i) + (1 - x_j) \;\forall\, i, j \in I$$
$$u_i - u_j \geq -\alpha - (1 - x_i) - (1 - x_j) \;\forall\, i, j \in I$$

(O6)

- Minimize the total distance.
- Add a constraint that assigns every district to nearest open shelter area
  - "Closest assignment" constraints.
- Define:
  - $distSorted_{ij}$: i[th] closest candidate location index to district j
- Add constraints:

$$y_{distSorted(1,j),j} = x_{distSorted(1,j)} \qquad \forall\, j \in J$$

$$y_{distSorted(i,j),j} \geq x_{distSorted(i,j)} - \sum_{k=1}^{i-1} x_{distSorted(k,j)}$$

(O1) Revisited

- $\mathbf{max}(\mathbf{min}(\boldsymbol{w_i} * \boldsymbol{x_i} + (\mathbf{1} - \boldsymbol{x_i}) \mid \boldsymbol{i} \in \boldsymbol{I}))$
- Must linearize and define an upper bound
- New decision variable: *minWeight*
- Objective function: **maximize minWeight**
- Define upper bound with a constraint
- Add:

$$\mathbf{MinWeight} \leq \boldsymbol{x_i} * \boldsymbol{w_i} + (\mathbf{1} - \boldsymbol{x_i}) \quad \forall\, \boldsymbol{i} \in \boldsymbol{I}$$

Mathematical Model

$$Max \quad MinWeight$$

$$s.t.$$

$$MinWeight \le W_i X_i + (1 - X_i) \qquad \forall i$$

$$\sum_{j \in J} dem_j y_{ij} + utilspace_i X_i \le Cap_i X_i \qquad \forall i$$

$$\sum_{i \in I} y_{ij} = 1 \qquad \forall j$$

$$u_i = \frac{\sum_{j \in J} y_{ij} * Demand_j}{Cap_i} \qquad \forall i$$

$$u_i \ge \beta X_i \qquad \forall i$$

$$u_i - u_j \le \alpha + (1 - X_i) + (1 - X_j) \qquad \forall i, j$$

$$u_i - u_j \ge -\alpha - (1 - X_i) - (1 - X_j) \qquad \forall i, j$$

$$\text{Max} \quad MinWeight$$

Maximize the minimum weight of operating shelter areas

$$s.t.$$

$$MinWeight \le W_i X_i + (1 - X_i) \qquad \forall i$$

Objective function linearization

$$\sum_{j \in J} dem_j y_{ij} + utilspace_i X_i \le Cap_i X_i \qquad \forall i$$

$$\sum_{i \in I} y_{ij} = 1 \qquad \forall j$$

$$u_i = \frac{\sum_{j \in J} y_{ij} * Demand_j}{Cap_i} \qquad \forall i$$

$$u_i \ge \beta X_i \qquad \forall i$$

$$u_i - u_j \le \alpha + (1 - X_i) + (1 - X_j) \qquad \forall i, j$$

$$u_i - u_j \ge -\alpha - (1 - X_i) - (1 - X_j) \qquad \forall i, j$$

$$Max \quad MinWeight$$

$$s.t.$$

$$MinWeight \leq W_i X_i + (1 - X_i) \qquad \forall i$$

$$\sum_{j \in J} dem_j y_{ij} + utilspace_i X_i \leq Cap_i X_i \qquad \forall i$$

Capacity

$$\sum_{i \in I} y_{ij} = 1 \qquad \forall j$$

$$u_i = \frac{\sum_{j \in J} y_{ij} * Demand_j}{Cap_i} \qquad \forall i$$

$$u_i \geq \beta X_i \qquad \forall i$$

$$u_i - u_j \leq \alpha + (1 - X_i) + (1 - X_j) \qquad \forall i,j$$

$$u_i - u_j \geq -\alpha - (1 - X_i) - (1 - X_j) \qquad \forall i,j$$

$$\begin{aligned}
&\mathrm{Max} \quad MinWeight \\
&s.t. \\
&MinWeight \leq W_i X_i + (1 - X_i) && \forall i \\
&\sum_{j \in J} dem_j y_{ij} + utilspace_i X_i \leq Cap_i X_i && \forall i \\
&\sum_{i \in I} y_{ij} = 1 && \forall j
\end{aligned}$$

Assign every district

$$u_i = \frac{\sum_{j \in J} y_{ij} * Demand_j}{Cap_i} \qquad \forall i$$

$$\begin{aligned}
&u_i \geq \beta X_i && \forall i \\
&u_i - u_j \leq \alpha + (1 - X_i) + (1 - X_j) && \forall i,j \\
&u_i - u_j \geq -\alpha - (1 - X_i) - (1 - X_j) && \forall i,j
\end{aligned}$$

$$Max \quad MinWeight$$

$$s.t.$$

$$MinWeight \le W_i X_i + (1 - X_i) \qquad \forall i$$

$$\sum_{j \in J} dem_j y_{ij} + utilspace_i X_i \le Cap_i X_i \qquad \forall i$$

$$\sum_{i \in I} y_{ij} = 1 \qquad \forall j$$

$$u_i = \frac{\sum_{j \in J} y_{ij} * Demand_j}{Cap_i} \qquad \forall i$$

Calculate utility

$$u_i \ge \beta X_i \qquad \forall i$$

$$u_i - u_j \le \alpha + (1 - X_i) + (1 - X_j) \qquad \forall i,j$$

$$u_i - u_j \ge -\alpha - (1 - X_i) - (1 - X_j) \qquad \forall i,j$$

$$Max \quad MinWeight$$

$$s.t.$$

$$MinWeight \le W_i X_i + (1 - X_i) \qquad \forall i$$

$$\sum_{j \in J} dem_j y_{ij} + utilspace_i X_i \le Cap_i X_i \qquad \forall i$$

$$\sum_{i \in I} y_{ij} = 1 \qquad \forall j$$

$$u_i = \frac{\sum_{j \in J} y_{ij} * Demand_j}{Cap_i} \qquad \forall i$$

$$u_i \ge \beta X_i \qquad \forall i$$

Minimum utility requirement

$$u_i - u_j \le \alpha + (1 - X_i) + (1 - X_j) \qquad \forall i,j$$

$$u_i - u_j \ge -\alpha - (1 - X_i) - (1 - X_j) \qquad \forall i,j$$

$$Max \quad MinWeight$$

$$s.t.$$

$$MinWeight \leq W_i X_i + (1 - X_i) \qquad \forall i$$

$$\sum_{j \in J} dem_j y_{ij} + utilspace_i X_i \leq Cap_i X_i \qquad \forall i$$

$$\sum_{i \in I} y_{ij} = 1 \qquad \forall j$$

$$u_i = \frac{\sum_{j \in J} y_{ij} * Demand_j}{Cap_i} \qquad \forall i$$

$$u_i \geq \beta X_i \qquad \forall i$$

$$u_i - u_j \leq \alpha + (1 - X_i) + (1 - X_j) \qquad \forall i,j$$

$$u_i - u_j \geq -\alpha - (1 - X_i) - (1 - X_j) \qquad \forall i,j$$

Pairwise differences of utilization levels

Distance requirements

$$d_i^{health} X_i \leq DistHealth \qquad \forall i$$

$$d_i^{road} X_i \leq DistRoad \qquad \forall i$$

$$y_{Sorted(1,j),j} = X_{Sorted(1,j)} \qquad \forall j$$

$$y_{Sorted(i,j),j} \geq X_{Sorted(i,j)} - \sum_{k=1}^{i-1} X_{Sorted(k,j)} \qquad \forall j$$

$$X_i \in \{0,1\} \qquad \forall i$$

$$y_{ij} \in \{0,1\} \qquad \forall i,j$$

$$u_i \geq 0 \qquad \forall i$$

$$d_i^{health} X_i \le DistHealth \qquad \forall i$$

$$d_i^{road} X_i \le DistRoad \qquad \forall i$$

$$y_{Sorted(1,j),j} = X_{Sorted(1,j)} \qquad \forall j$$

$$y_{Sorted(i,j),j} \ge X_{Sorted(i,j)} - \sum_{k=1}^{i-1} X_{Sorted(k,j)} \qquad \forall j$$

Closest assignment

$$X_i \in \{0,1\} \qquad \forall i$$

$$y_{ij} \in \{0,1\} \qquad \forall i,j$$

$$u_i \ge 0 \qquad \forall i$$

$$d_i^{health} X_i \leq DistHealth \qquad \forall i$$

$$d_i^{road} X_i \leq DistRoad \qquad \forall i$$

$$y_{Sorted(1,j),j} = X_{Sorted(1,j)} \qquad \forall j$$

$$y_{Sorted(i,j),j} \geq X_{Sorted(i,j)} - \sum_{k=1}^{i-1} X_{Sorted(k,j)} \qquad \forall j$$

$$X_i \in \{0,1\} \qquad \forall i$$

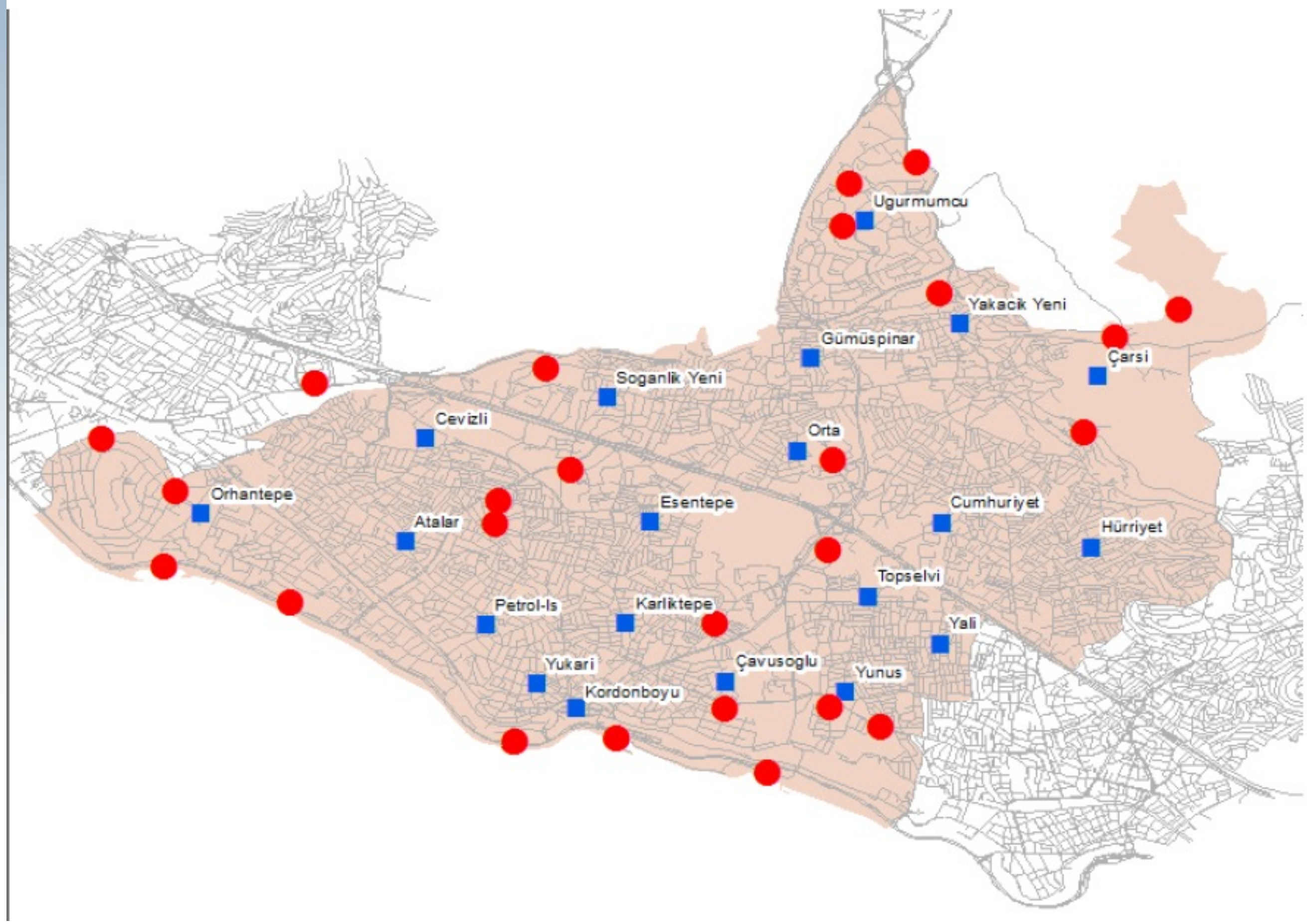
$$y_{ij} \in \{0,1\} \qquad \forall i,j$$

$$u_i \geq 0 \qquad \forall i$$

Domain constraints

Computational Study

- Model is tested on a sample data on Kartal, Istanbul.
- 25 potential shelter areas
- 20 districts



Results

- Generated 3000 instances by varying *DistHealth*, *DistRoad*, *β*, and *α*.
- Solved using Gurobi integrated with DSS
- The objective value decreases as *β* is increased and *α*, *DistHealth* and *DistRoad* are decreased.
- This is expected as these changes tighten the feasible set.

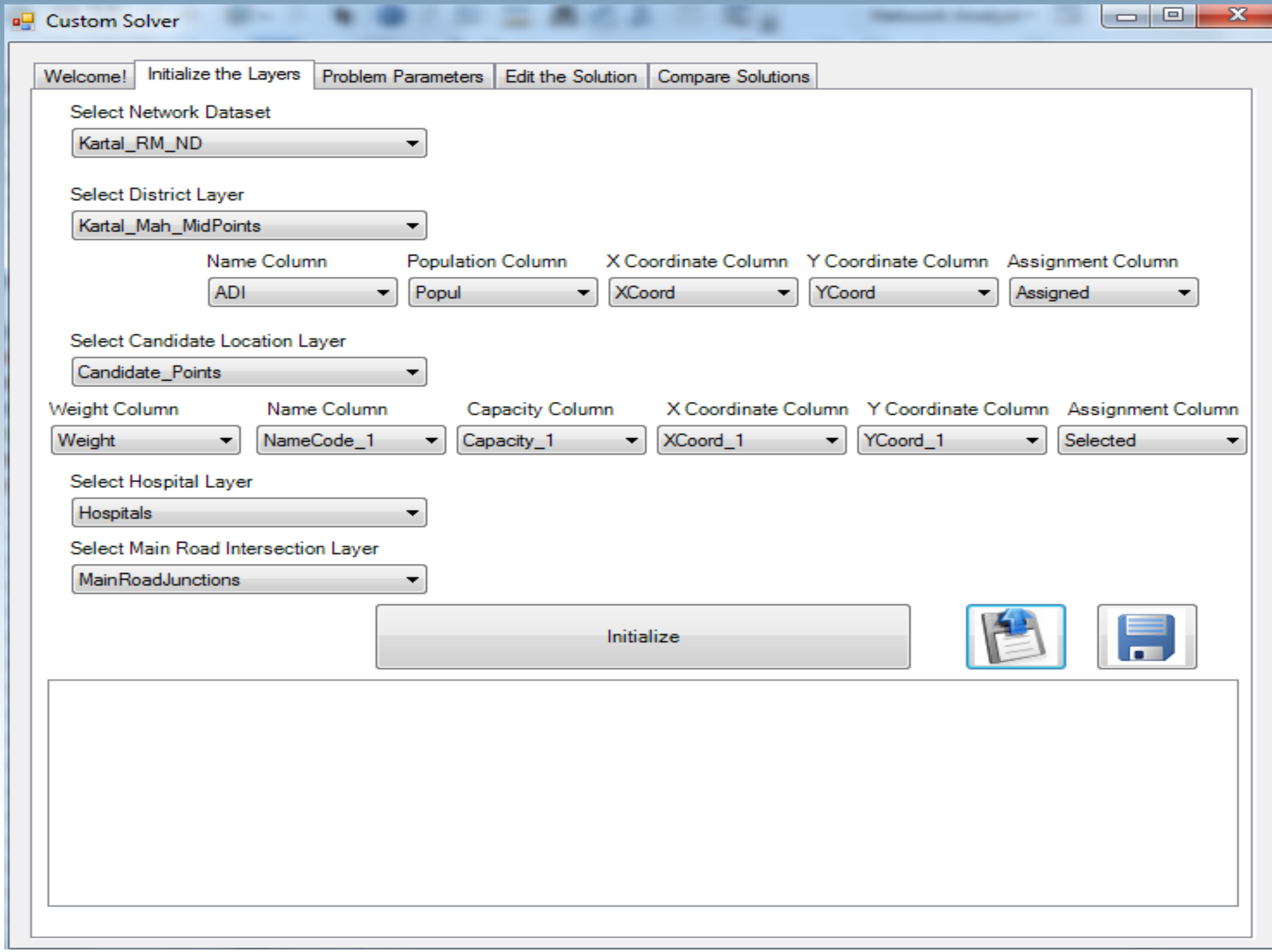
Decision Support System

- An ArcGIS extension that utilizes Gurobi and developed in C#
- The user
    - Can solve the mathematical model
    - Edit the solution
    - Save the current solution
    - Compare up to 4 solutions
    - Visualize the current solution
    - Graph the shelter area utilizations
    - See the lists of assignments

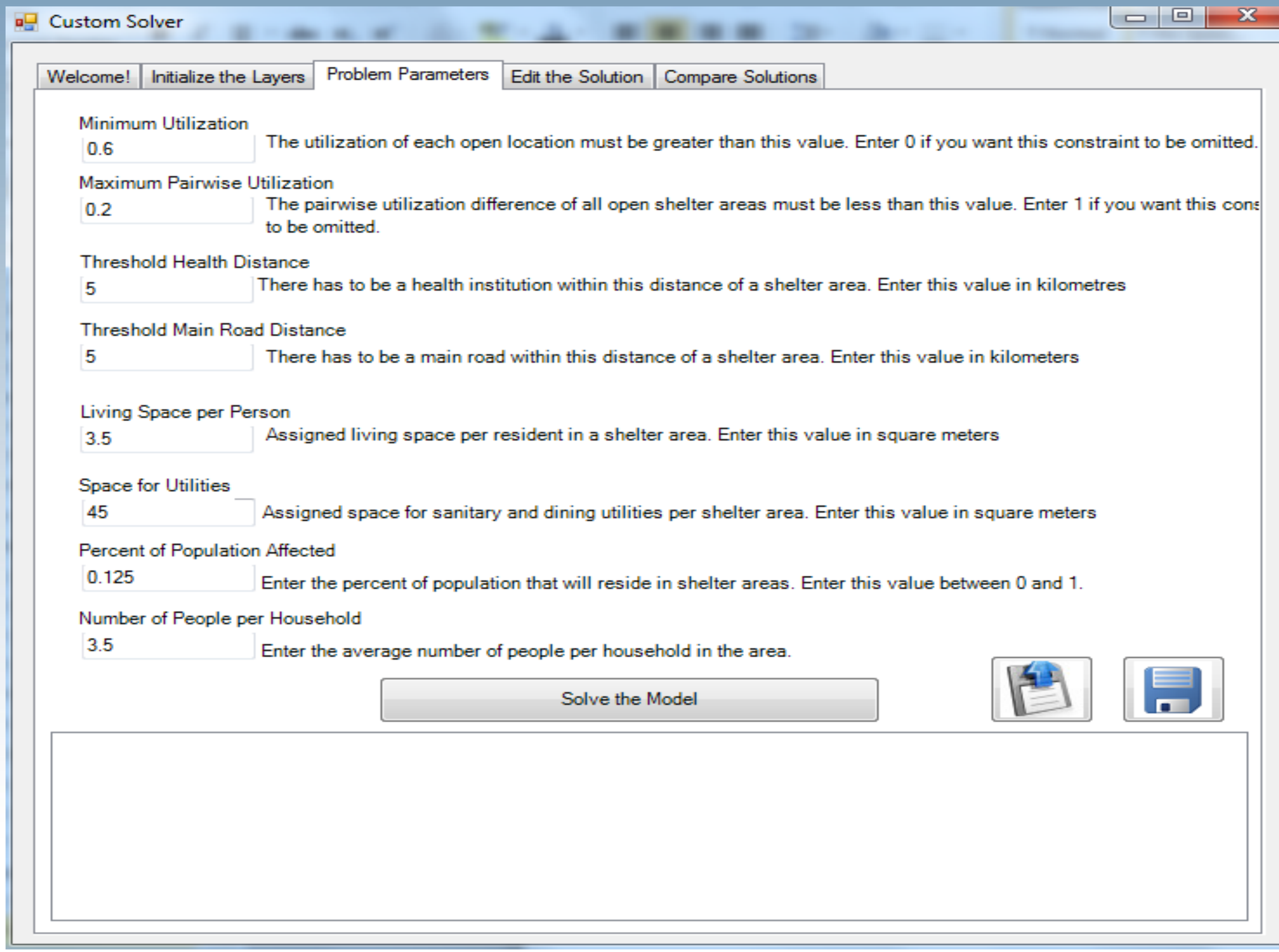
Decision Support System

- 5 layers needed:
  - Location of districts with population data in its data table
  - Location of candidate shelter areas with has weight and capacity data in its data table
  - A layer that contains the hospitals
  - A layer that contains the main road junctions
  - A “Network Dataset” that contains the road network

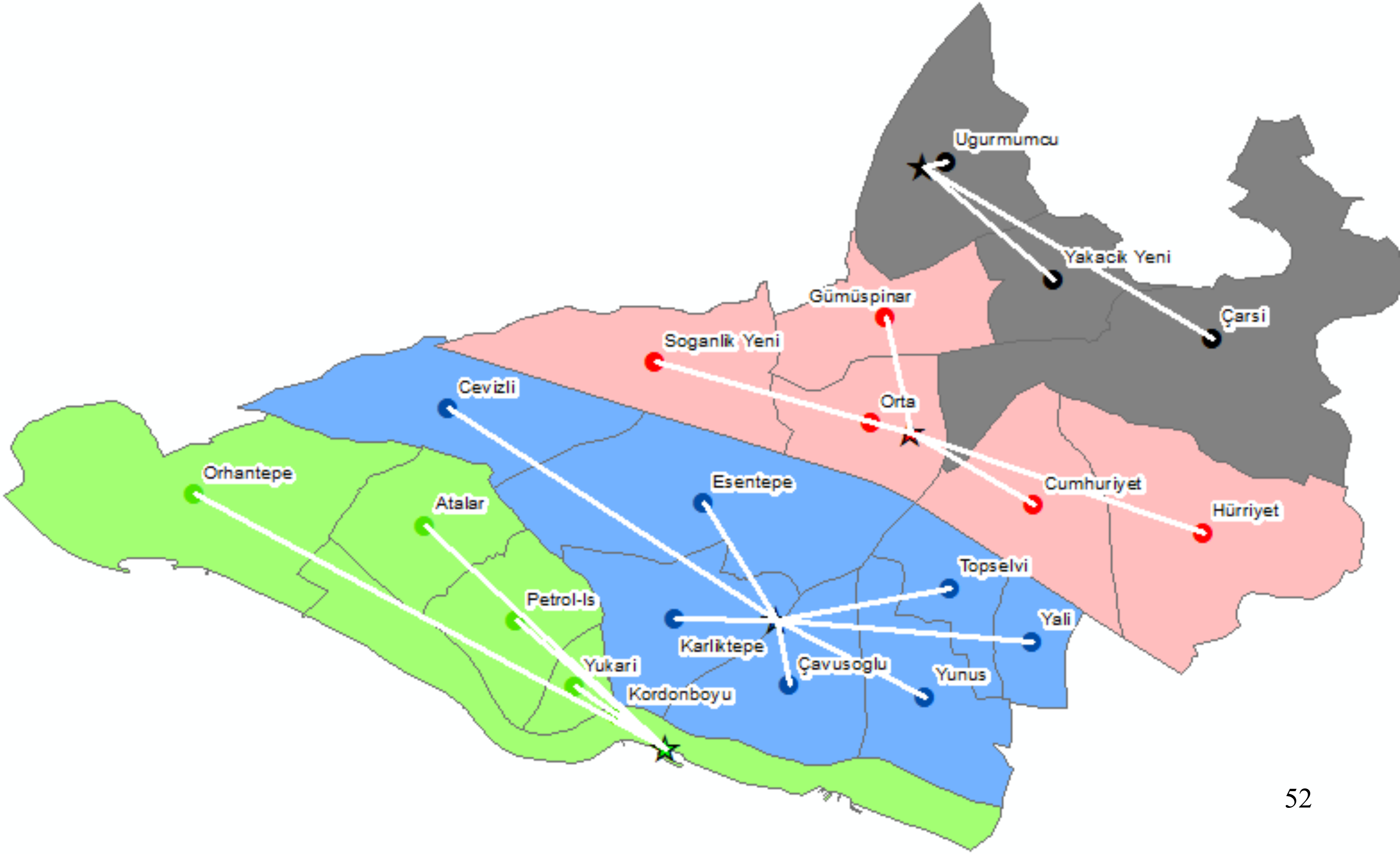
Decision Support System



Decision Support System



Decision Support System



Conclusion

- In this study, a mathematical model to capture the requirements of TRC is formulated
- To implement the mathematical model, a decision support system via GIS is developed
- Tested with TRC personnel.