

Locating Temporary Shelter Areas after a Large-Scale Disaster

Fırat Kılıcı

Bahar Yetiş Kara, Burçin Bozkaya



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**

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

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

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,

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



Objective Functions

- Maximize the minimum weight of operating areas.

$$\text{Maximize} \\ (\min(w_i * x_i + (1 - x_i) \mid i \in I)) \quad (OI)$$



Objective Functions

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

- *minimize* $\sum_{i \in I} d_{health}^i * x_i$ (O2)

- *minimize* $\sum_{i \in I} d_{road}^i * x_i$ (O3)



Objective Functions

- Maximize the total utilization of open shelter areas.

$$\textit{maximize } \sum_{i \in I} u_i * x_i \quad (\text{O4})$$



Objective Functions

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

$$\textit{minimize} \sum_{i \in I} \sum_{\substack{k \in I \\ k < i}} (u_i - u_k) * x_i * x_k$$

(O5)



Objective Functions

- Minimize the total distance

$$\textit{minimize} \sum_{i \in I} \sum_{j \in J} \textit{dist}_{ij} * x_{ij} \quad (\text{O6})$$



Selecting the Best Objective

- Select one objective function for the model
- Introduce other five objectives as constraints
- Choose OI 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:

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



(O5)

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

- How to linearize?
 1. Multiplication of many variables
 2. Absolute value linearization



(O5)

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

- How to linearize?

I. Multiplication of many variables

$$\text{If } x_i = 1 \text{ and } x_j = 1 \Rightarrow |u_i - u_j| \leq \alpha$$



(O5)

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

- How to linearize?

I. Multiplication of many variables

$$\text{If } x_i = 1 \text{ and } x_j = 1 \Rightarrow |u_i - u_j| \leq \alpha$$

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



(O5)

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

- How to linearize?

2. Absolute value linearization

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

(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:

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

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



(OI) Revisited

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

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

Mathematical Model





Max *MinWeight*

s.t.

$$\text{MinWeight} \leq W_i X_i + (1 - X_i) \quad \forall i$$

$$\sum_{j \in J} \text{demand}_j y_{ij} + \text{utilspace}_i X_i \leq \text{Cap}_i X_i \quad \forall i$$

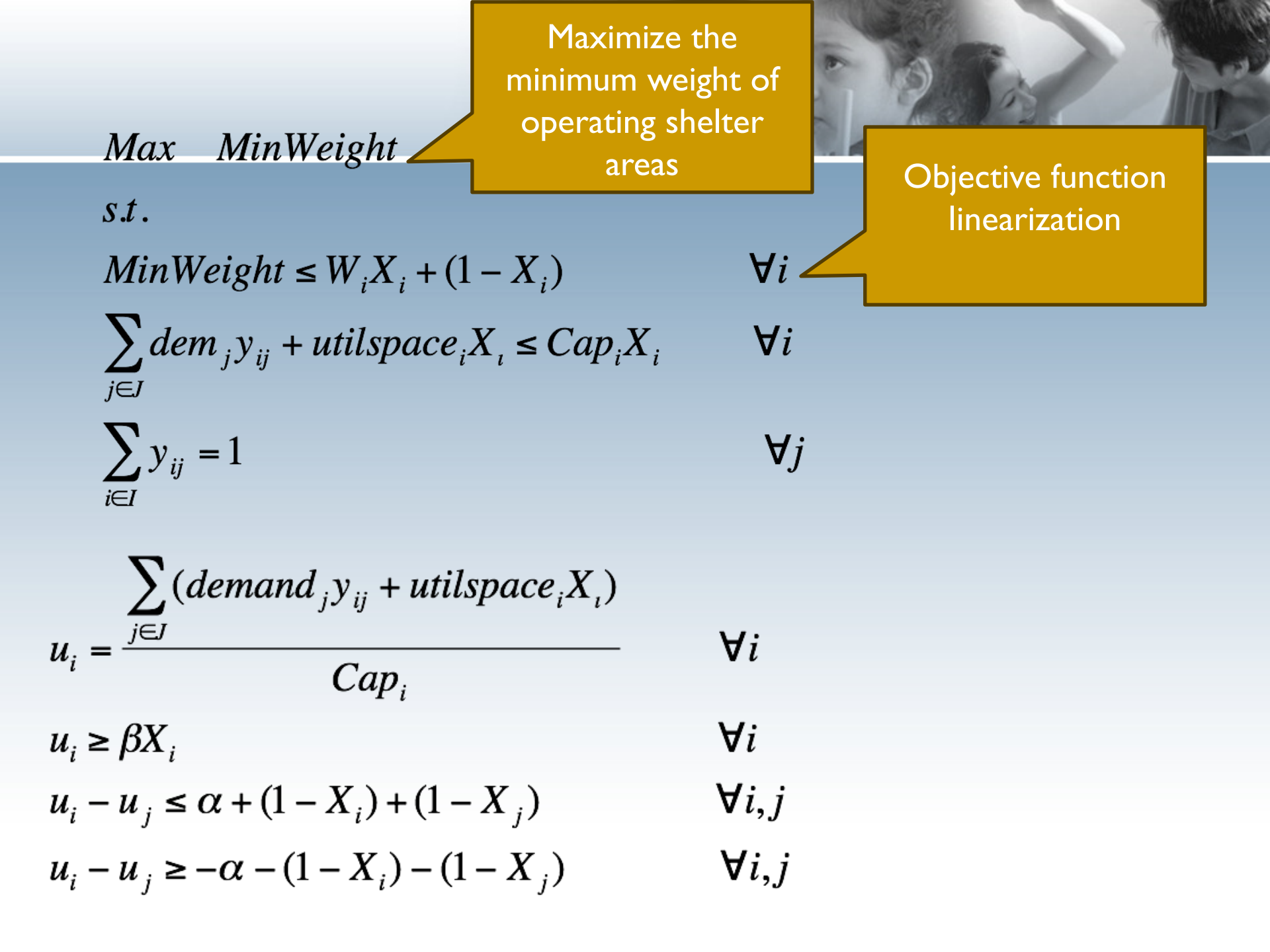
$$\sum_{i \in I} y_{ij} = 1 \quad \forall j$$

$$u_i = \frac{\sum_{j \in J} (\text{demand}_j y_{ij} + \text{utilspace}_i X_i)}{\text{Cap}_i} \quad \forall i$$

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

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

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



Maximize the
minimum weight of
operating shelter
areas

Objective function
linearization

Max MinWeight

s.t.

$$\text{MinWeight} \leq W_i X_i + (1 - X_i)$$

$\forall i$

$$\sum_{j \in J} \text{dem}_j y_{ij} + \text{utilspace}_i X_i \leq \text{Cap}_i X_i$$

$\forall i$

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

$\forall j$

$$u_i = \frac{\sum_{j \in J} (\text{demand}_j y_{ij} + \text{utilspace}_i X_i)}{\text{Cap}_i}$$

$\forall i$

$$u_i \geq \beta X_i$$

$\forall i$

$$u_i - u_j \leq \alpha + (1 - X_i) + (1 - X_j)$$

$\forall i, j$

$$u_i - u_j \geq -\alpha - (1 - X_i) - (1 - X_j)$$

$\forall i, j$



Max *MinWeight*

s.t.

$$\text{MinWeight} \leq W_i X_i + (1 - X_i)$$

$\forall i$

Capacity

$$\sum_{j \in J} \text{demand}_j y_{ij} + \text{utilspace}_i X_i \leq \text{Cap}_i X_i$$

$\forall i$

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

$\forall j$

$$u_i = \frac{\sum_{j \in J} (\text{demand}_j y_{ij} + \text{utilspace}_i X_i)}{\text{Cap}_i}$$

$\forall i$

$$u_i \geq \beta X_i$$

$\forall i$

$$u_i - u_j \leq \alpha + (1 - X_i) + (1 - X_j)$$

$\forall i, j$

$$u_i - u_j \geq -\alpha - (1 - X_i) - (1 - X_j)$$

$\forall i, j$



Max *MinWeight*

s.t.

$$\text{MinWeight} \leq W_i X_i + (1 - X_i) \quad \forall i$$

$$\sum_{j \in J} \text{dem}_j y_{ij} + \text{utilspace}_i X_i \leq \text{Cap}_i X_i \quad \forall i$$

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

Assign every
district

$$u_i = \frac{\sum_{j \in J} (\text{demand}_j y_{ij} + \text{utilspace}_i X_i)}{\text{Cap}_i} \quad \forall i$$

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

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

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



Max *MinWeight*

s.t.

$$\text{MinWeight} \leq W_i X_i + (1 - X_i) \quad \forall i$$

$$\sum_{j \in J} \text{demand}_j y_{ij} + \text{utilspace}_i X_i \leq \text{Cap}_i X_i \quad \forall i$$

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

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

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

Calculate utility



Max *MinWeight*

s.t.

$$\text{MinWeight} \leq W_i X_i + (1 - X_i) \quad \forall i$$

$$\sum_{j \in J} \text{demand}_j y_{ij} + \text{utilspace}_i X_i \leq \text{Cap}_i X_i \quad \forall i$$

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

$$u_i = \frac{\sum_{j \in J} (\text{demand}_j y_{ij} + \text{utilspace}_i X_i)}{\text{Cap}_i} \quad \forall i$$

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

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

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

Minimum utility
requirement



Max *MinWeight*

s.t.

$$\text{MinWeight} \leq W_i X_i + (1 - X_i) \quad \forall i$$

$$\sum_{j \in J} \text{demand}_j y_{ij} + \text{utilspace}_i X_i \leq \text{Cap}_i X_i \quad \forall i$$

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

$$u_i = \frac{\sum_{j \in J} (\text{demand}_j y_{ij} + \text{utilspace}_i X_i)}{\text{Cap}_i} \quad \forall i$$

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

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

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

Pairwise
differences of
utilization
levels



Distance
requirements

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

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

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

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

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

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

$$u_i \geq 0 \quad \forall i$$



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

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

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

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

Closest
assignment

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

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

$$u_i \geq 0 \quad \forall i$$



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

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

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

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

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

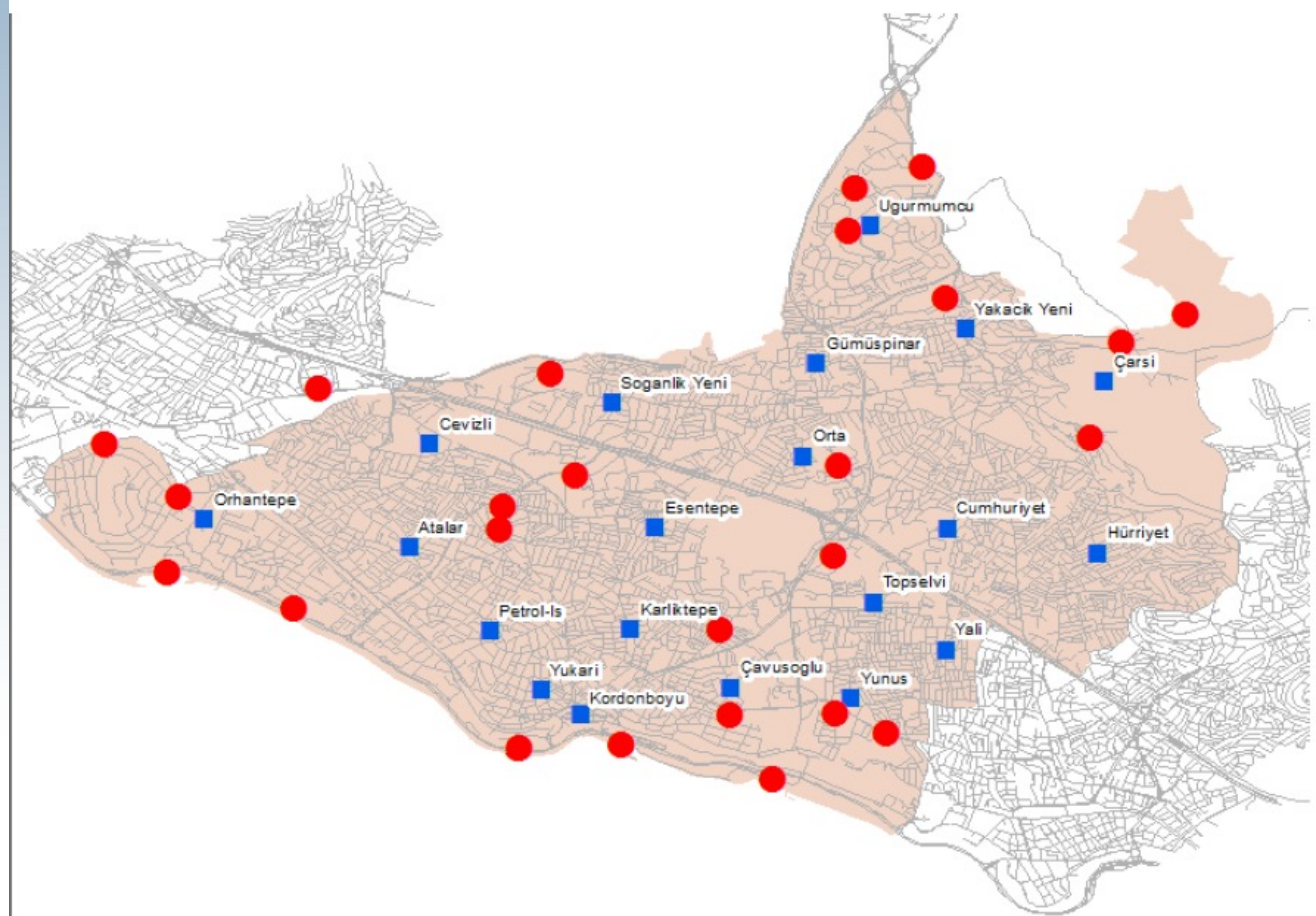
$$y_{ij} \in \{0,1\} \quad \forall i,j$$

$$u_i \geq 0 \quad \forall i$$

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

Custom Solver

Welcome! Initialize the Layers Problem Parameters Edit the Solution Compare Solutions

Select Network Dataset
Kartal_RM_ND

Select District Layer
Kartal_Mah_MidPoints

Name Column Population Column X Coordinate Column Y Coordinate Column Assignment Column
ADI Popul XCoord YCoord Assigned

Select Candidate Location Layer
Candidate_Points

Weight Column Name Column Capacity Column X Coordinate Column Y Coordinate Column Assignment Column
Weight NameCode_1 Capacity_1 XCoord_1 YCoord_1 Selected

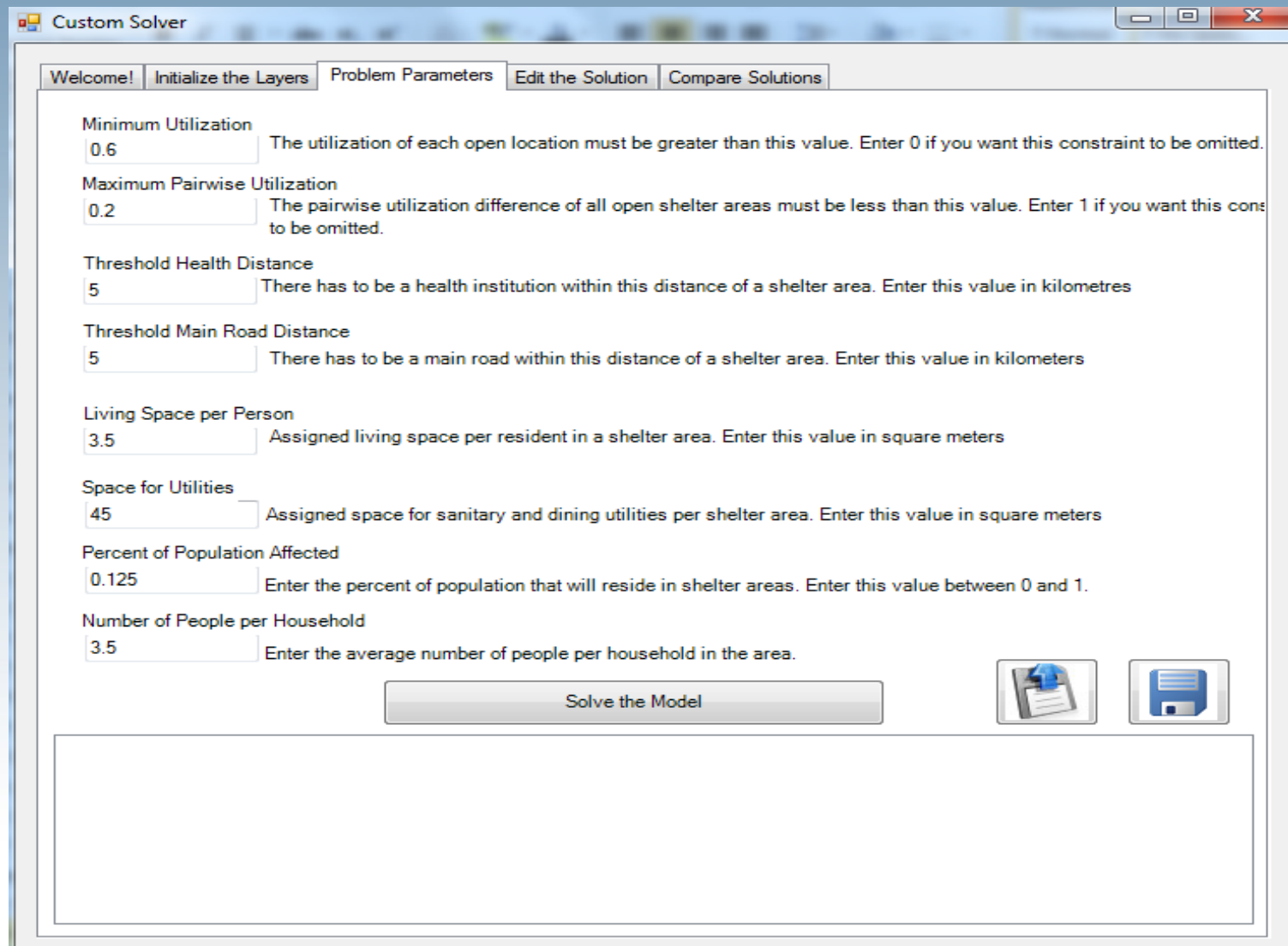
Select Hospital Layer
Hospitals

Select Main Road Intersection Layer
MainRoadJunctions

Initialize

Decision Support System



Custom Solver

Welcome! | Initialize the Layers | Problem Parameters | Edit the Solution | Compare Solutions

Minimum Utilization
0.6 The utilization of each open location must be greater than this value. Enter 0 if you want this constraint to be omitted.

Maximum Pairwise Utilization
0.2 The pairwise utilization difference of all open shelter areas must be less than this value. Enter 1 if you want this constraint to be omitted.

Threshold Health Distance
5 There has to be a health institution within this distance of a shelter area. Enter this value in kilometres

Threshold Main Road Distance
5 There has to be a main road within this distance of a shelter area. Enter this value in kilometers

Living Space per Person
3.5 Assigned living space per resident in a shelter area. Enter this value in square meters

Space for Utilities
45 Assigned space for sanitary and dining utilities per shelter area. Enter this value in square meters

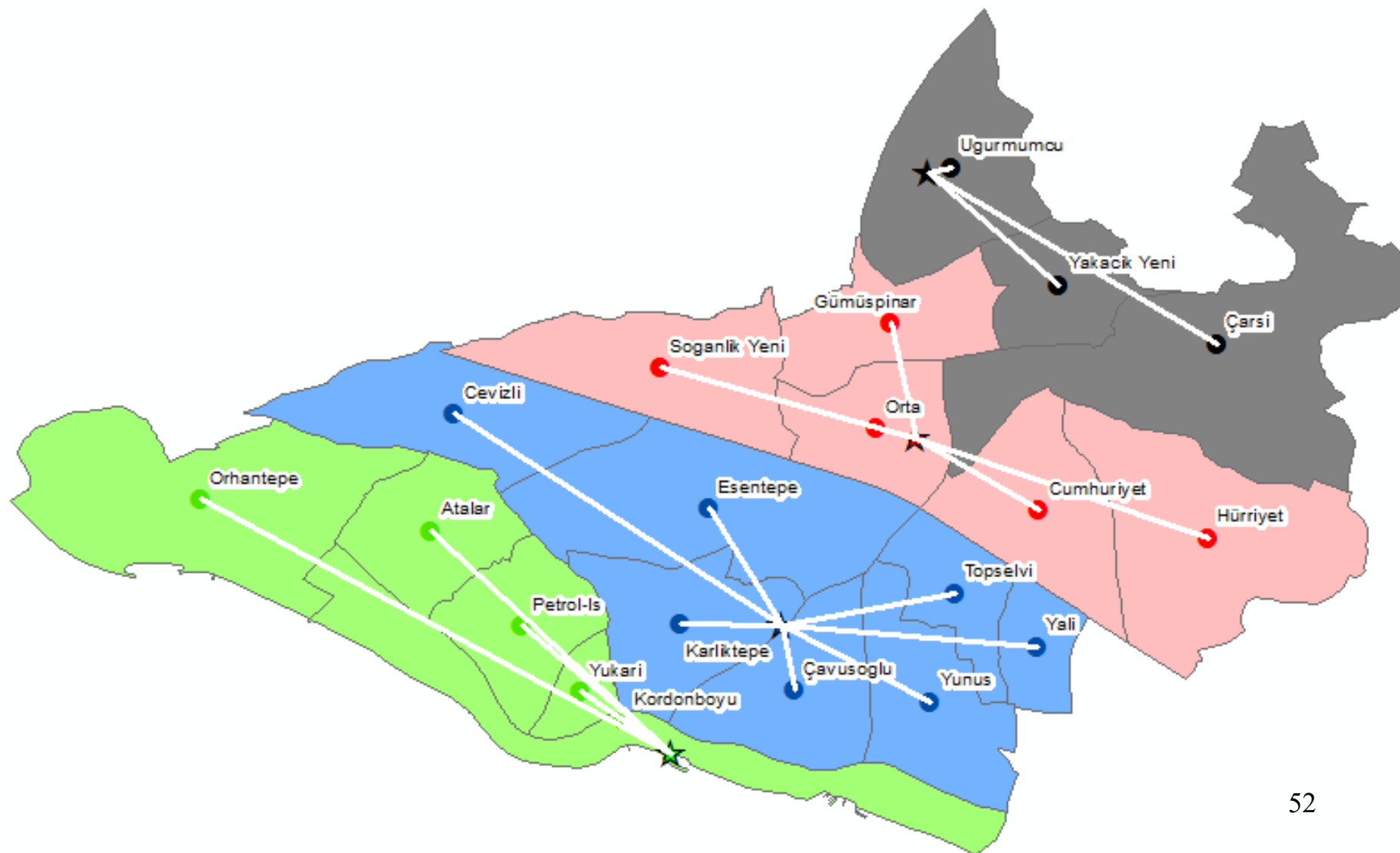
Percent of Population Affected
0.125 Enter the percent of population that will reside in shelter areas. Enter this value between 0 and 1.

Number of People per Household
3.5 Enter the average number of people per household in the area.

Solve the Model

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.