ORGAN TRANSPLANTATION LOGISTICS

CASE FOR TURKEY

6/29/2012

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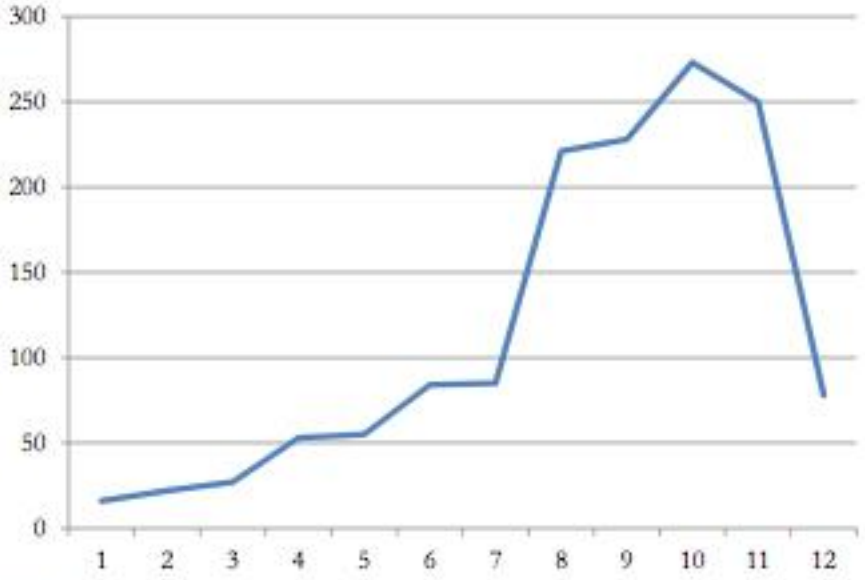
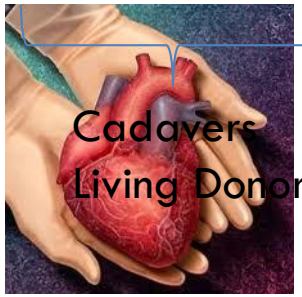
General Information-What is Organ Transplantation?



Organ Transplantation

- Treatment technique
- Donor

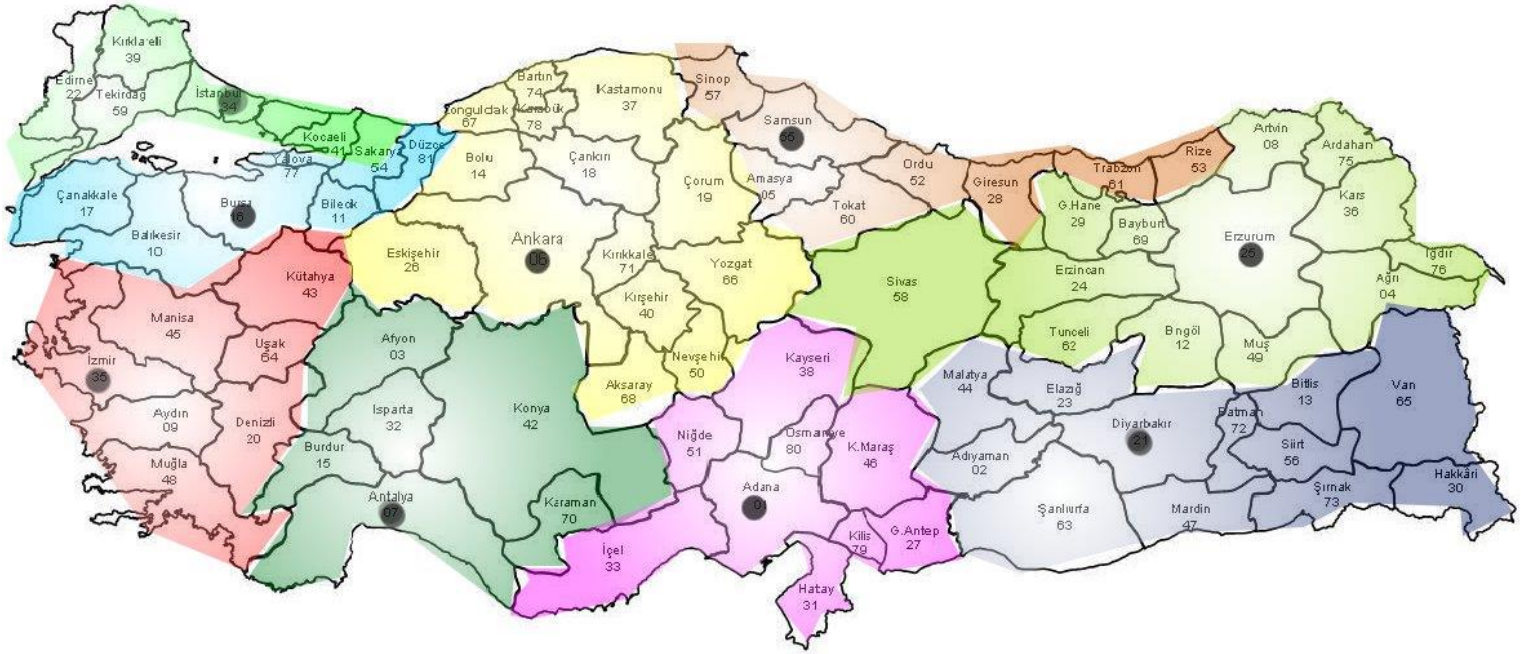


Patient (Recipient)

- increases life standard of the patient
- only way to treat patient

Organ Transplantation

- Ministry of Health
- National Coordination Center
- Regional Coordination Center (9)



Organ Transplantation System

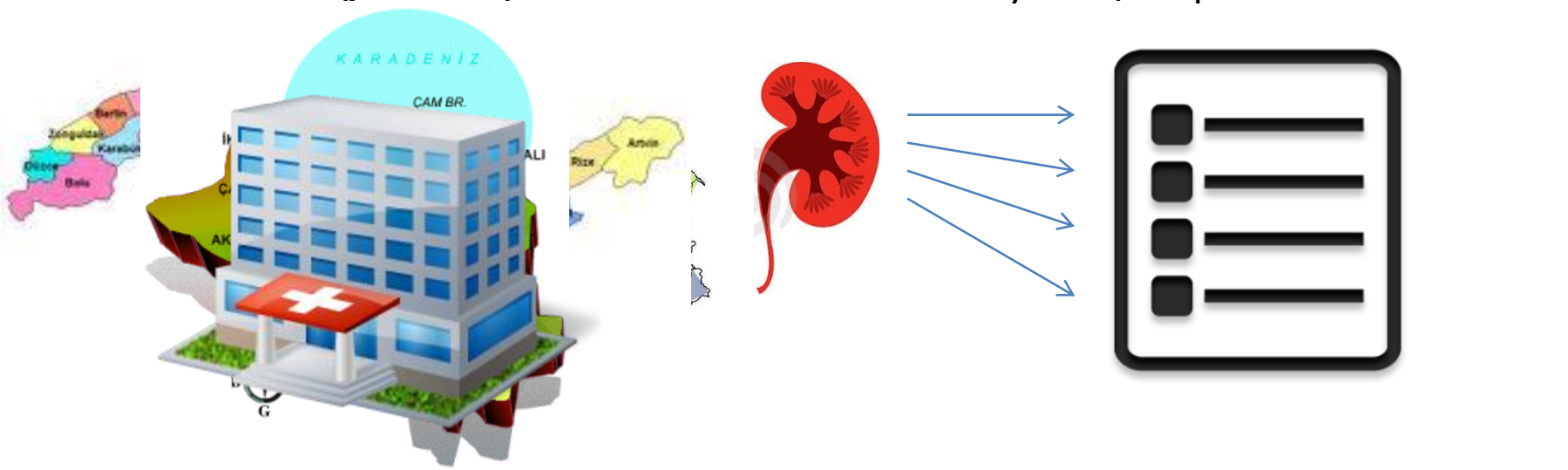
- Hospitals having operating room (donor)
- Transplantation centers
  - Heart: 5 cities, 14 centers
  - Liver: 9 cities, 34 centers
  - Kidney: 19 cities, 59 centers

  } waiting lists (recipient)

- How are donor and recipient matched?

Matching- Hierarchical Method

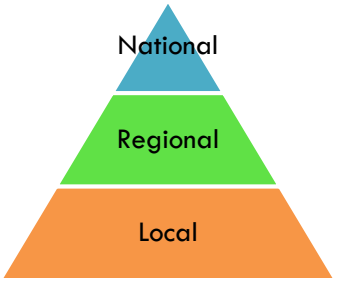
- 4 types of lists: patient, transplantation center, city, RCC
- 4 Layer



Organ Transplantation Procedure

Emergent Case → Recipient City

Normal Case → Matching Operation → Vehicle Selection → Recipient City

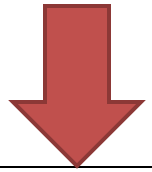


Fact

- Huge gap: number of donors vs. number of patients in the waiting lists
- Worldwide problem
- In Turkey
  - 3930 donors in 2011
  - 20954 patients in April 2012
- Perfect structured system to prevent each donated organ to be perished

Perishability

- Ischemia Time
  - Organ state time without blood circulation
  - Varies for each organ
    - Heart: 5 hours
    - Liver: 12 hours
    - Kidney: 18 hours



	Organ Removal Surgery Time	Time Left for Transportation	Organ Implementation Surgery Time
Heart	10	220	70
Liver	45	405	270
Kidney	60	570	450

Problem Definition

- Hierarchical structure
  - Considers fairness at national level
  - Lists
- Clusters have important role
- Clusters lead
  - Number of potential donor
  - Number of candidate recipient
  - Unfairness
- Transportation option
  - Heart and liver cannot be satisfied by highway transportation for some regions

Problem Definition

- a new modeling strategy to find the best RCC locations
- The main issues to consider are:
  - Availability of the transportation vehicle (car, helicopter, airplane)
  - The ischemia time of organs
  - Availability of specialized hospitals
  - The supply and demand of the organs

Model Development

- Mathematical Models
  - Model 1: Only highway distance
  - Model 2: Two mode transportation
  - Equity constraints
- Simulation Model
  - Representation of the organ transplantation system in abstract level

Model 1

Sets

i: supply node set
(81 city)

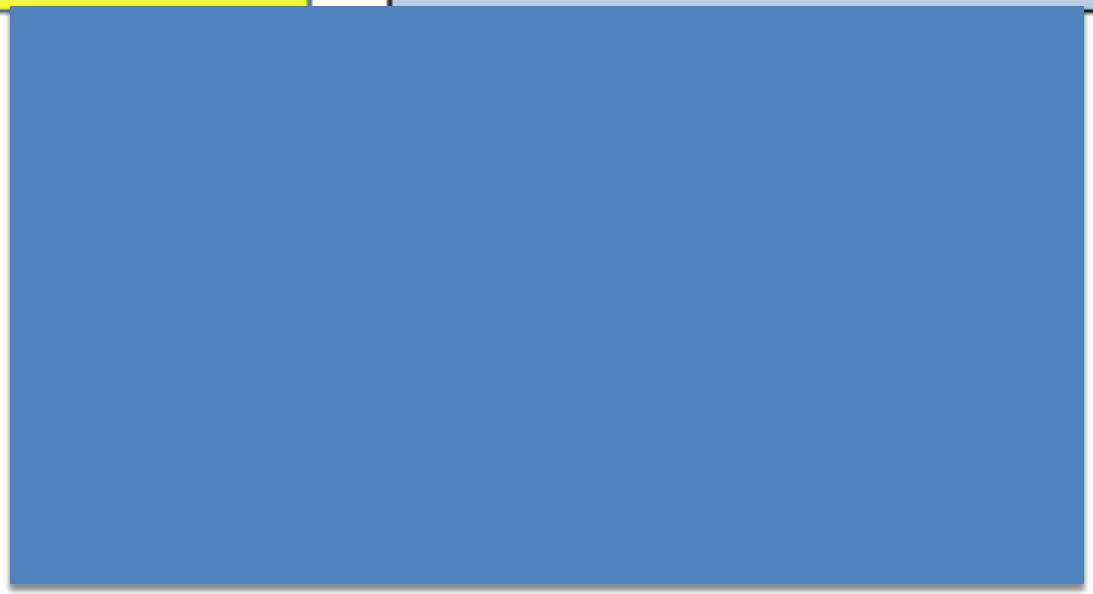
j: demand node set
(19 city)

k: RCC node set
(19 city)

Alias(i,s)

Parameters

O(i): supply of donated organs
b(i,s): travel time between nodes (by highway)
u(i,s): helicopter travel time between nodes
d(i): demand of nodes (population/10000)
p: #of RCC's
h: # of helicopters in total
T: ischemia time (time bound to travel between cities)



Model 1

Model 1

$$\max \sum_{i,j,k} O_i d_j y_{ij}^k$$

- $\sum_{k=1}^{19} x_{ik} = 1$
- $\sum_{k=1}^{19} z_k \leq p$
- $y_{ij}^k = x_{ik} . x_{jk}$
- $y_{ij}^k \leq z_k$
- $x_{ik} \leq z_k$
- $b_{ij} . y_{ij}^k \leq T$

- $y_{ij}^k \leq \frac{x_{ik} + x_{jk}}{2}$
- $y_{ij}^k \geq (x_{ik} + x_{jk}) - 1$

Model 2

Model 1

Sets

i: supply node set
(81 city)
j: demand node set
(19 city)
k: RCC node set
(19 city)
Alias(i,s)

Parameters

O(i): supply of donated organs
b(i,s): travel time between nodes (by highway)
u(i,s): helicopter travel time between nodes
d(i): demand of nodes (population/10000)
p: #of RCC's
h: # of helicopters in total
T: ischemia time (time bound to travel between cities)

Variables

$$z_k: \begin{cases} 1 \text{ if } RCC \text{ is located at } k \\ 0 \text{ otherwise} \end{cases}$$

$$x_{ik}: \begin{cases} 1 \text{ if } i \text{ is served by RCC at } k \\ 0 \text{ otherwise} \end{cases}$$

$$y_{ij}^k: \begin{cases} 1 \text{ if } i \text{ supplies to demand node } j \text{ served by RCC } k \\ 0 \text{ otherwise} \end{cases}$$

$$hc_i: \begin{cases} 1 \text{ if helicopter exists at node } i \\ 0 \text{ otherwise} \end{cases}$$

Model 2

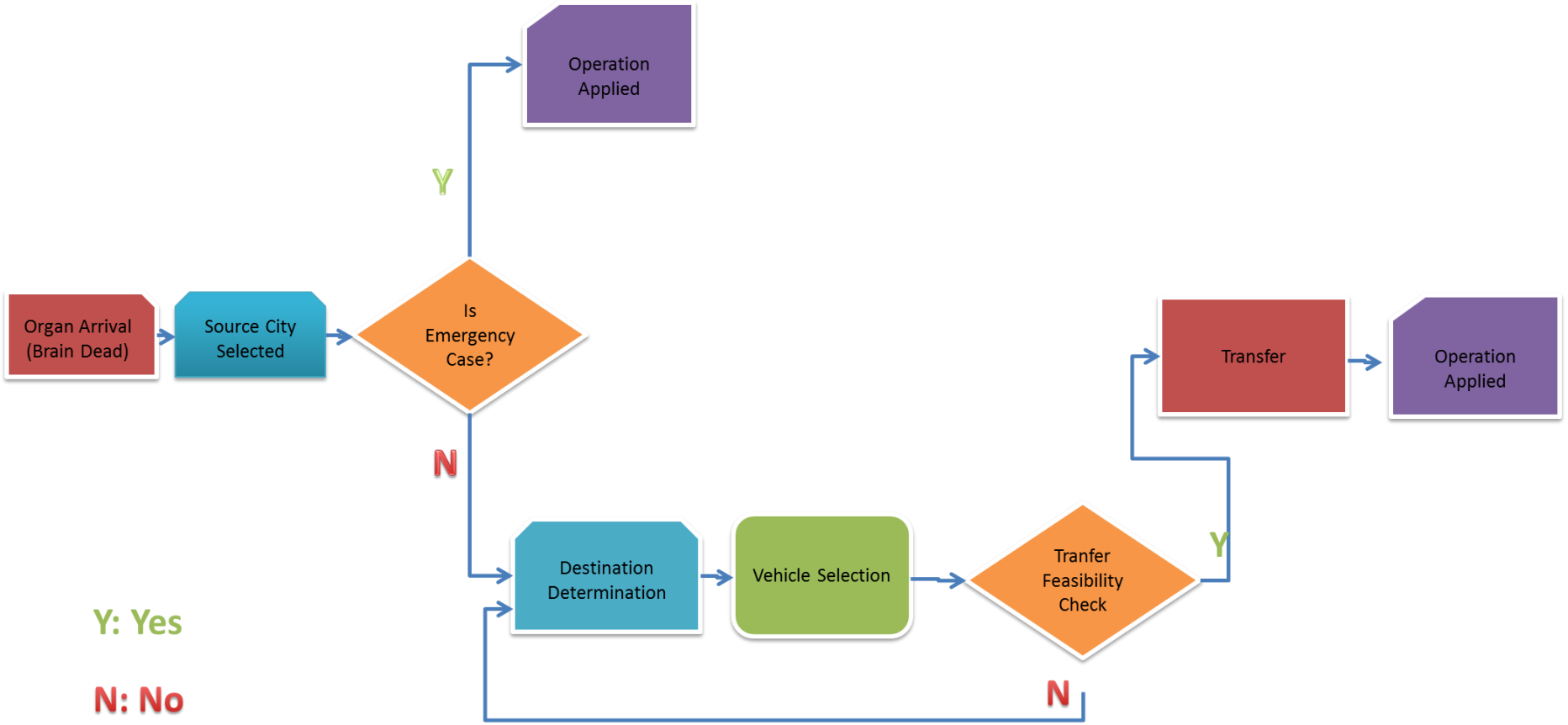
$$\max \sum_{i,j,k} O_i d_j y_{ij}^k$$

- $\sum_{k=1}^{19} x_{ik} = 1$
- $\sum_{k=1}^{19} z_k \leq p$
- $\sum_{i=1}^{81} hc_i \leq h$
- $y_{ij}^k \leq \frac{x_{ik}+x_{jk}}{2}$
- $y_{ij}^k \geq (x_{ik} + x_{jk}) - 1$
- $y_{ij}^k \leq z_k$
- $x_{ik} \leq z_k$
- $(b_{ij}.y_{ij}^k) - ((b_{ij} - u_{ij}).hc_i) \leq T$

Simulation Model

- To include stochastic nature of the organ transplantation system
- Observe the outcomes of the mathematical model in real life
  - Hierarchical structure of matching process

Simulation Model



Computational Results

- Turkey
  - 81 donor cities
  - 20 recipient cities
  - 20 candidate RCC locations
  - Turkish highway network (General Directorate of Highways)
    - 1/3 highway travel time for helicopter duration
    - 1/5 highway travel time for flight duration

Data

- General statistics about organ transplantation system
  - RCC based number of cadavers ratio
    - Ratio from living donors
      - Potential number of donor at each city
  - RCC based number of transplantation ratio
    - Number of transplantation centers at that RCC
    - Number of transplantation centers at recipient cities

Simulation Model

- Number of kidney donations
- Number of liver donations
- Number of heart donations

} From number of donors (2011)

- City assignment (based on empirical distribution)
- Emergent ratio/ Normal Case ratio with respect to organ type
- Matching operation

- Transportation option
  - Helicopter
  - Highway
  - Plane

Simulation Model

- Percentages of donated organs

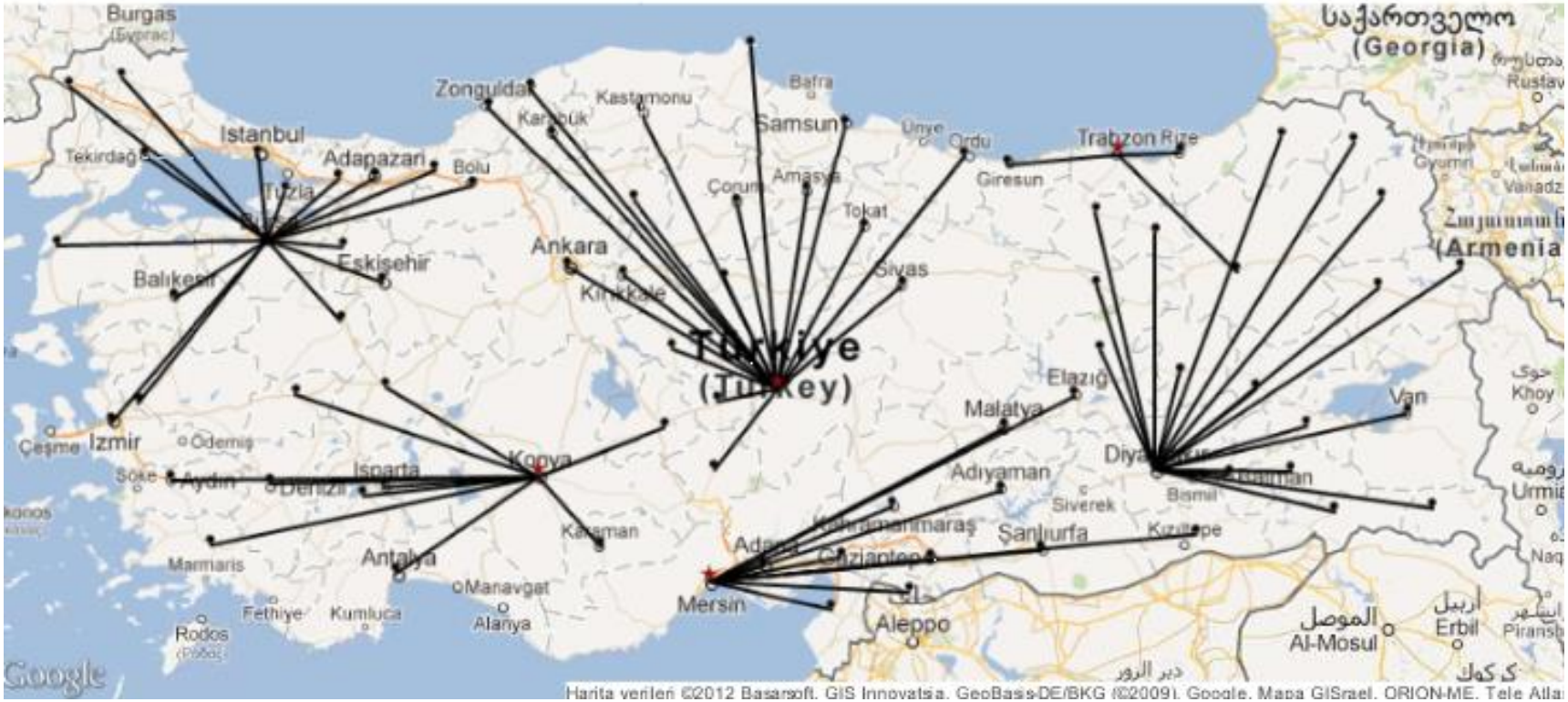
Donated Organ	Donation Percentage
Kidney	76,5 %
Liver	20,2 %
Heart	3,3 %

- Percentages of emergency cases with respect to organ type

Donated Organ	Emergency Cases
Kidney	1%
Liver	13%
Heart	86%

Model 1 Solutions

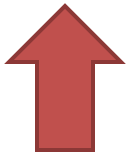
- T=405 (Liver Case), min. num. of p=6



Model 1 Results

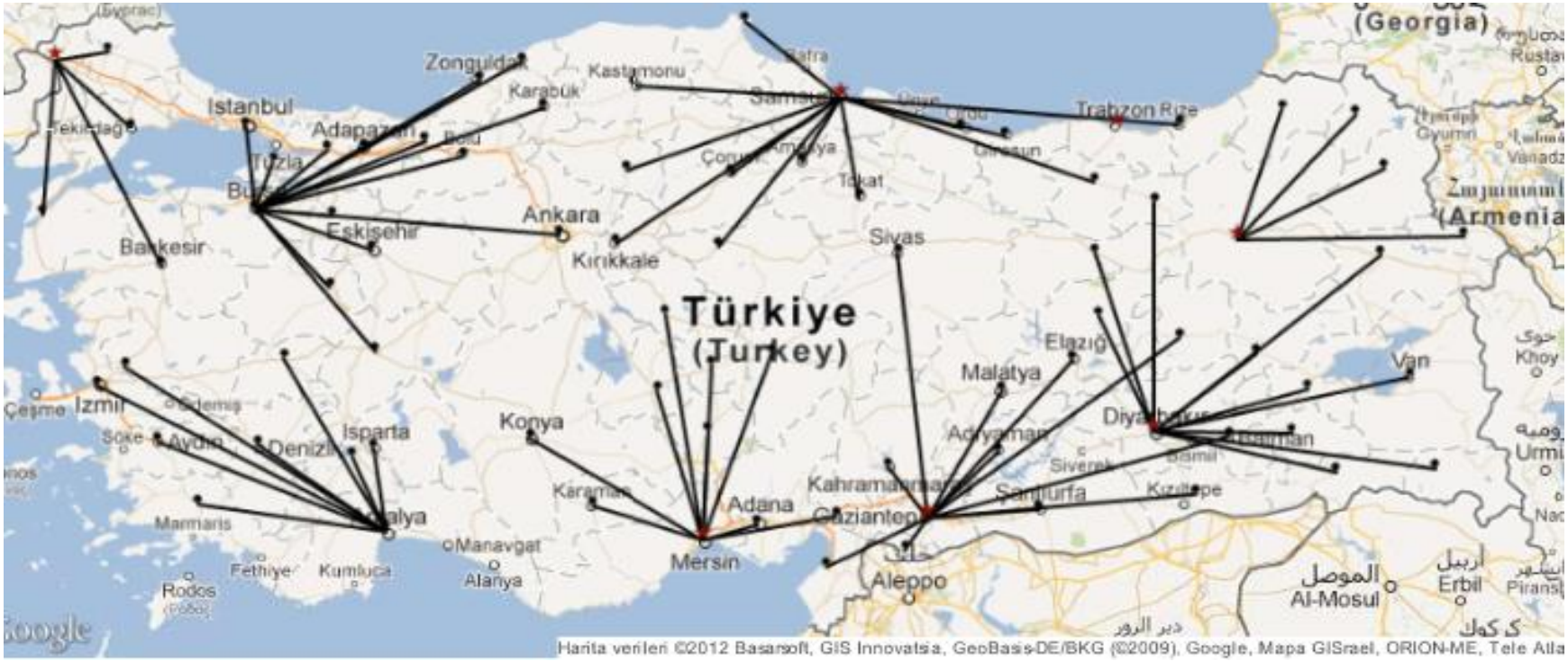
Organ	T	p	Objective Value
HEART	220	-	Infeasible
LIVER	405	6	1.99E+09
KIDNEY	570	4	3.35E+09

P	T	Objective Value
9	314	1.87E+09
6	374	1.94E+09
4	537	3.30E+09



Model 1 Solution

- For p=9, ischemia time bound is 314 minutes

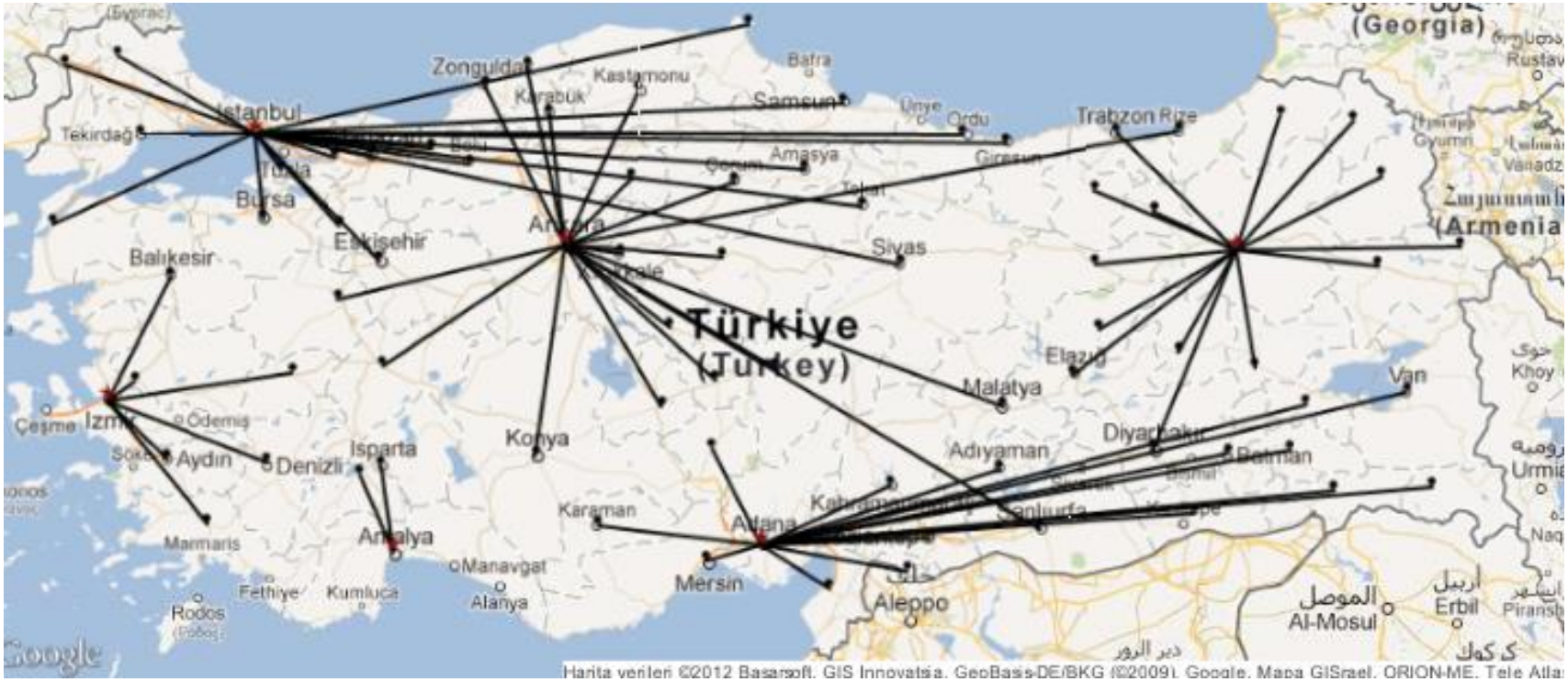


Model 2 Solutions

- Aim: find feasible solution for heart case
- 5 city have heart transplantation center
- Result: Infeasible
- Add one city from east part of Turkey having kidney transplantation center (Erzurum, Malatya, Diyarbakir and Gaziantep)

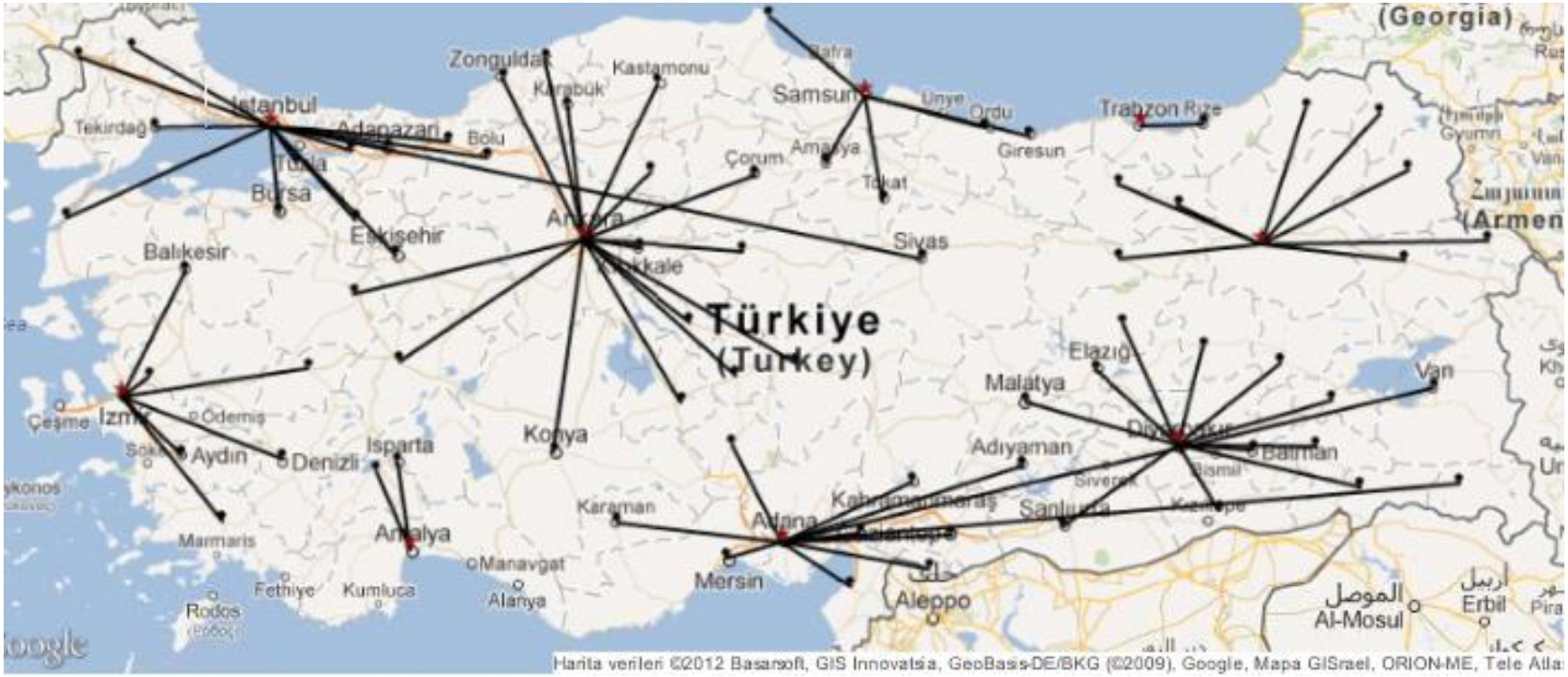
Model 2 Solution

- T=220, p=6, required helicopter:17

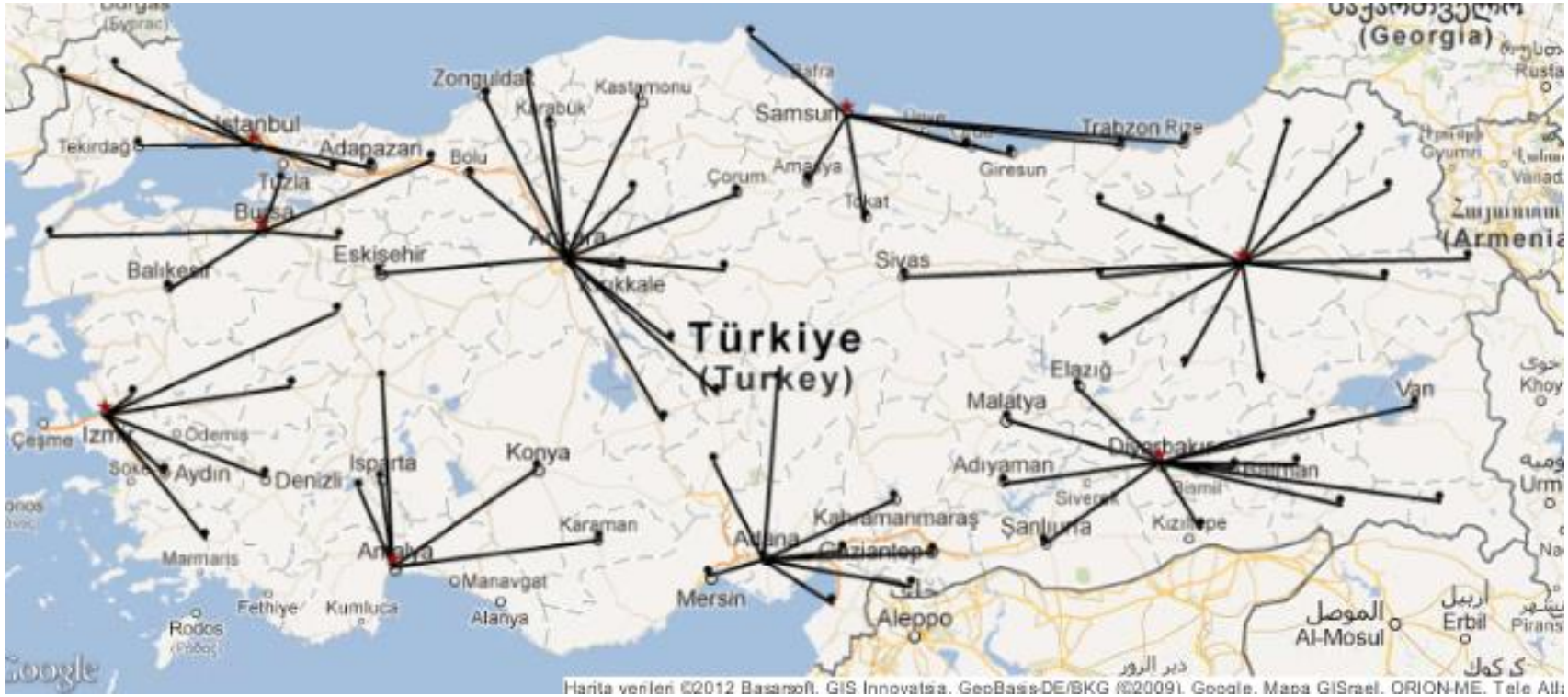


Model 2 Solution

- T=220 and p=9, helicopter 3, 5 of them are current locations



Current System



Current System vs. Proposed Solution

Organ	T	P	Current Obj.Val.	Proposed p	Proposed Obj. Val.
HEART	220	-	INF	-	INF
LIVER	405	9	INF	6	1.99E+09
KIDNEY	570	9	1.09E+09	4	3.35E+09

Current System vs. Proposed System

	Current System Solution		Proposed Solution	
p	T	Objective Value	T	Objective Value
9	481	1.09E+09	314	1.87E+09

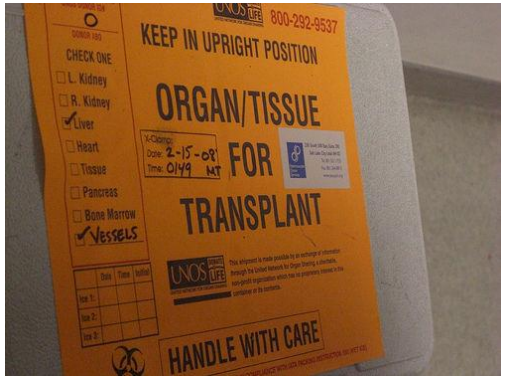
35 % ↓

58 % ↑

T	p	Helicopter	Obj. Val.
Current	9	8	1.09E+09
Proposed	9	3	1.28E+09

Conclusion

- Improvement in matching operations based on city allocation
- Increase in organ flow at each region (30% - 50%)
- Decrease travel time of organ
- New allocation brings more opportunities to increase the performance of organ transplantation system in Turkey



Thank You!

Simulation Model Outcomes

- Model 1 based outcomes
  - Kidney 98% , p=4, 61 planes
  - Liver 96%, p=6 , 41 planes
  - T=314 and p=9, 87 %, 120 planes, 1 organ dispose
  - Current system for kidney 89% , 100 planes
- Model 2 based outcomes p=9, T=220
- Proposed: 92% , helikopter usage 17 times with 3 helicopters
- Current system: 89% , helikopter usage 215 times with 8 helicopters