ORGAN TRANSPLANTATION LOGISTICS

CASE FOR TURKEY

6/29/2012

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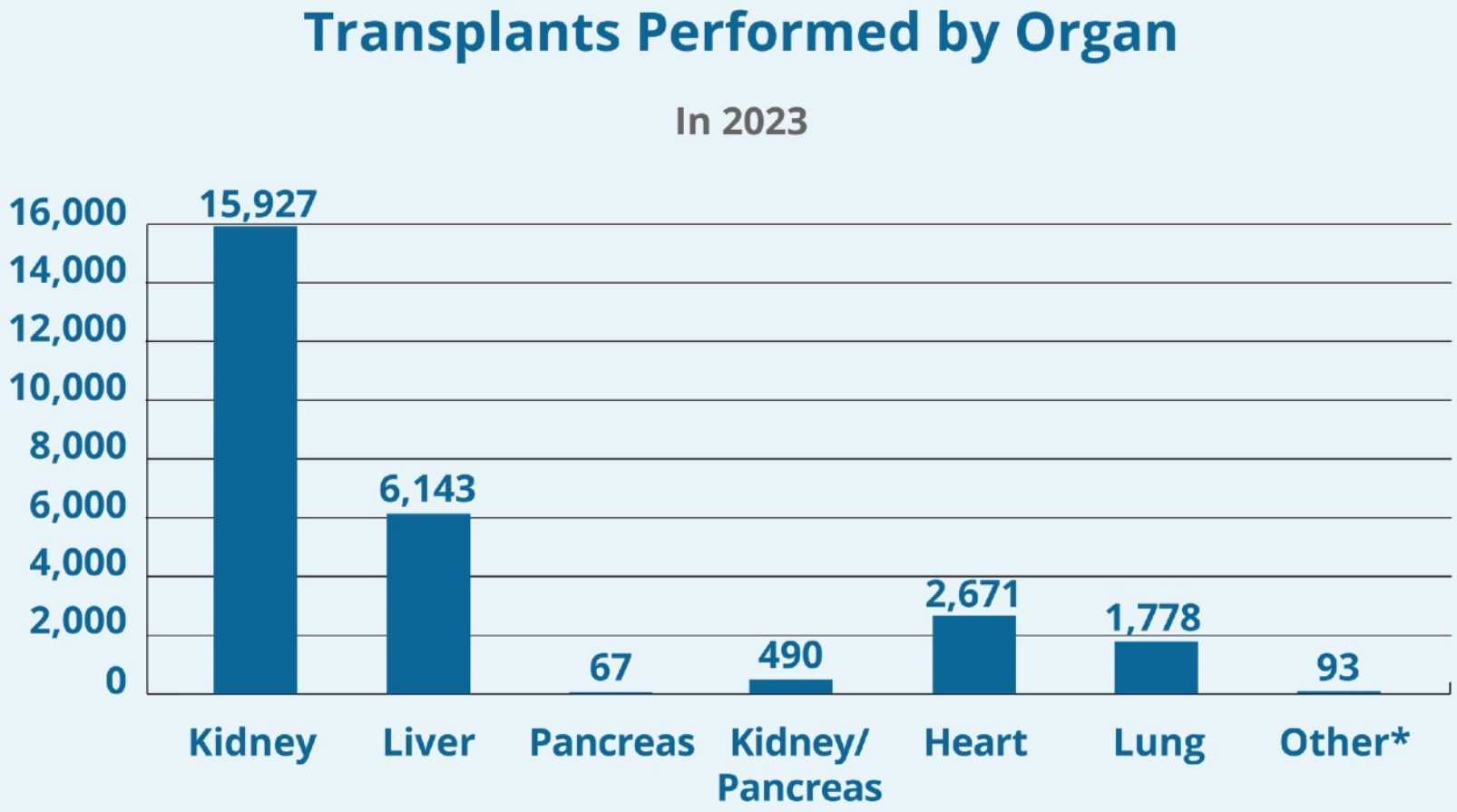
What is Organ Transplantation?

- **Organ transplantation** is a medical procedure in which an organ is removed from one body and placed in the body of a recipient, to replace a damaged or missing organ.
- Organs may be transported from a donor site to another location

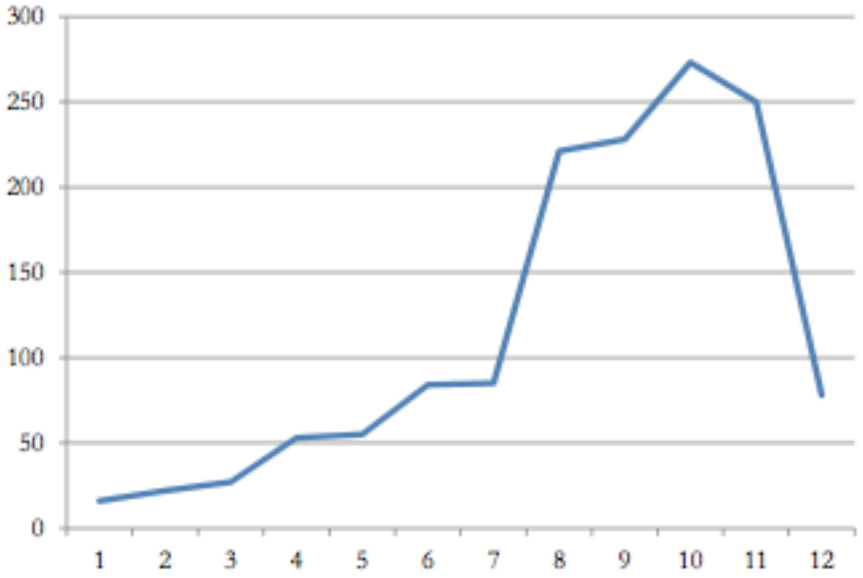
What is Organ Transplantation?



*Other includes kidney/pancreas and allograft transplants like face, hands, and abdominal wall.

Based on OPTN data as of September 3, 2023. Data subject to change based on future data submission or correction.
Totals may be less than the sums due to patients included in multiple categories.

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

- Treatment technique
- Donor

Patient (Recipient)

- increases life standard of the patient
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Organ Transplantation

- Treatment technique
- Donor

  Cadavers
  Living Donors

Patient (Recipient)

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

HOW DOES THE PROCESS WORK?

WAITING FOR A TRANSPLANT

When someone's organ fails, he or she may be evaluated for a potential transplant and placed on the national organ transplant waiting list.

The list is very long and not everyone survives while waiting for a donor.

Donors of all ages are needed.

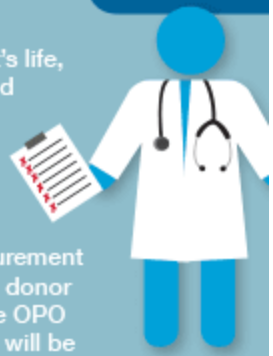
In the United States, it is illegal to buy or sell organs and tissue for transplantation.

BECOMING A DONOR

A person who has sustained a severe brain injury, such as from an accident, stroke or lack of oxygen, is put on artificial support.

There is no cost to the donor's family or estate for donation.

Doctors work hard to save the patient's life, but sometimes there is a complete and irreversible loss of brain function. The patient is declared clinically and legally dead. Only then is donation an option.



The hospital contacts the organ procurement organization (OPO), which checks the donor registry. If the person is registered, the OPO will inform the family. If not, the family will be asked to authorize donation.

Donation can provide solace to a grieving family.

All major religions support donation as a final act of compassion and generosity.

FINDING A MATCH

A national system matches available organs from the donor with people on the waiting list.

Race, income, gender, celebrity and social status are never considered.

SAVING LIVES

Once matches are found, the wait-listed patients are contacted by their transplant teams.

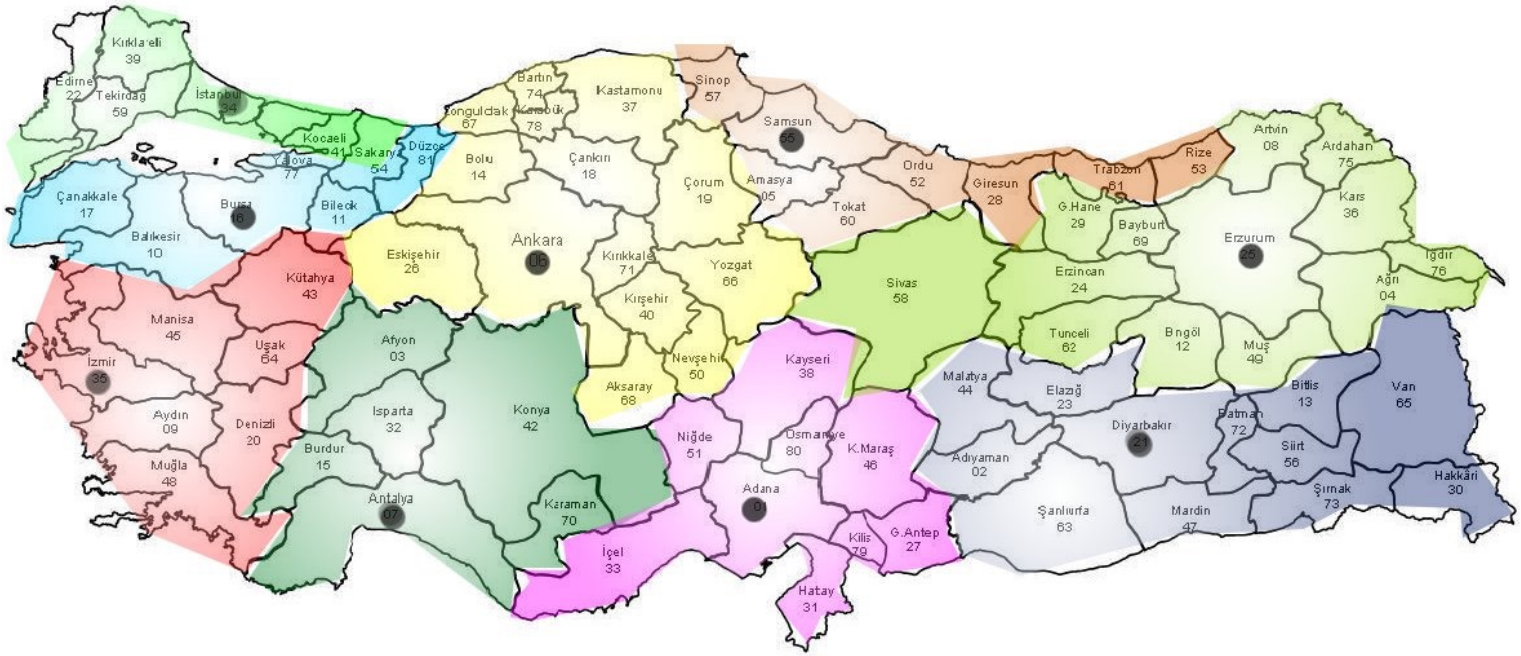
Organs are recovered from the donor with care and respect, and sent to hospitals for transplantation.

Transplants restore lives and return patients as active members of their families and communities.

Provided by Donate Life America 2016

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

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Layer 1: Hospital

Matching- Hierarchical Method

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Layer 1: Hospital

Hospital W - Patient List

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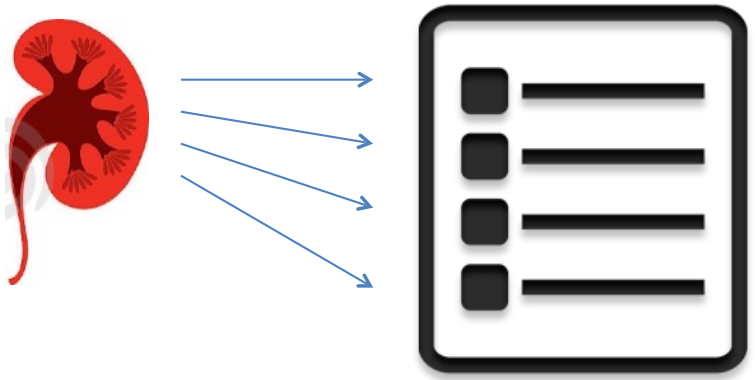

Matching- Hierarchical Method

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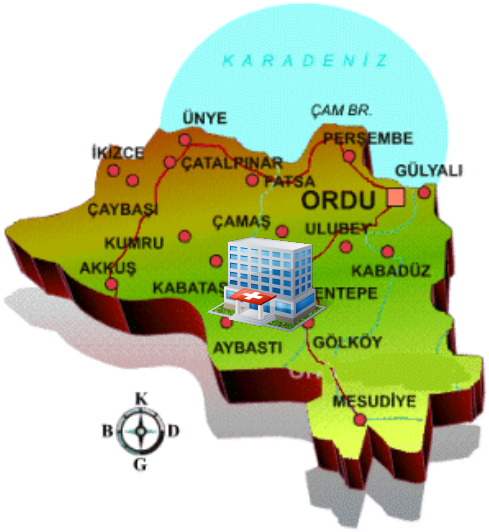
Layer 2: City



City Y – Transplantation Center List

Matching- Hierarchical Method

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Layer 4: NCC

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NCC: RCC List

Organ Transplantation Procedure

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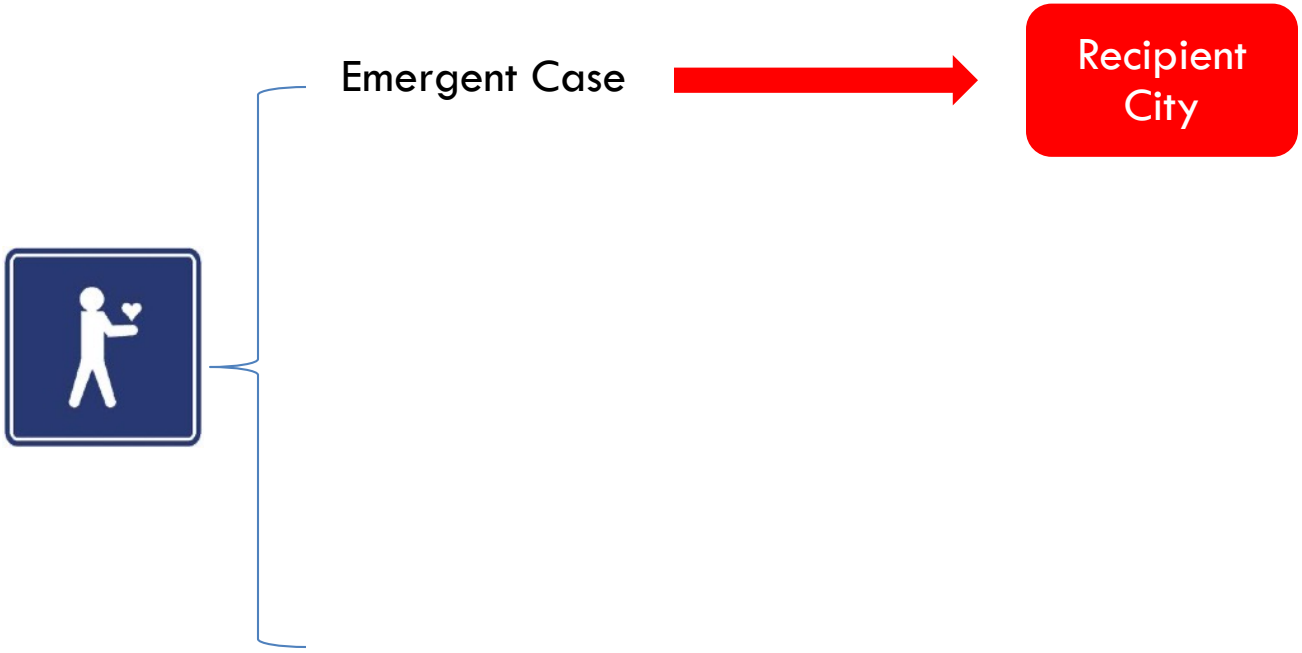
Emergent Case

Organ Transplantation Procedure



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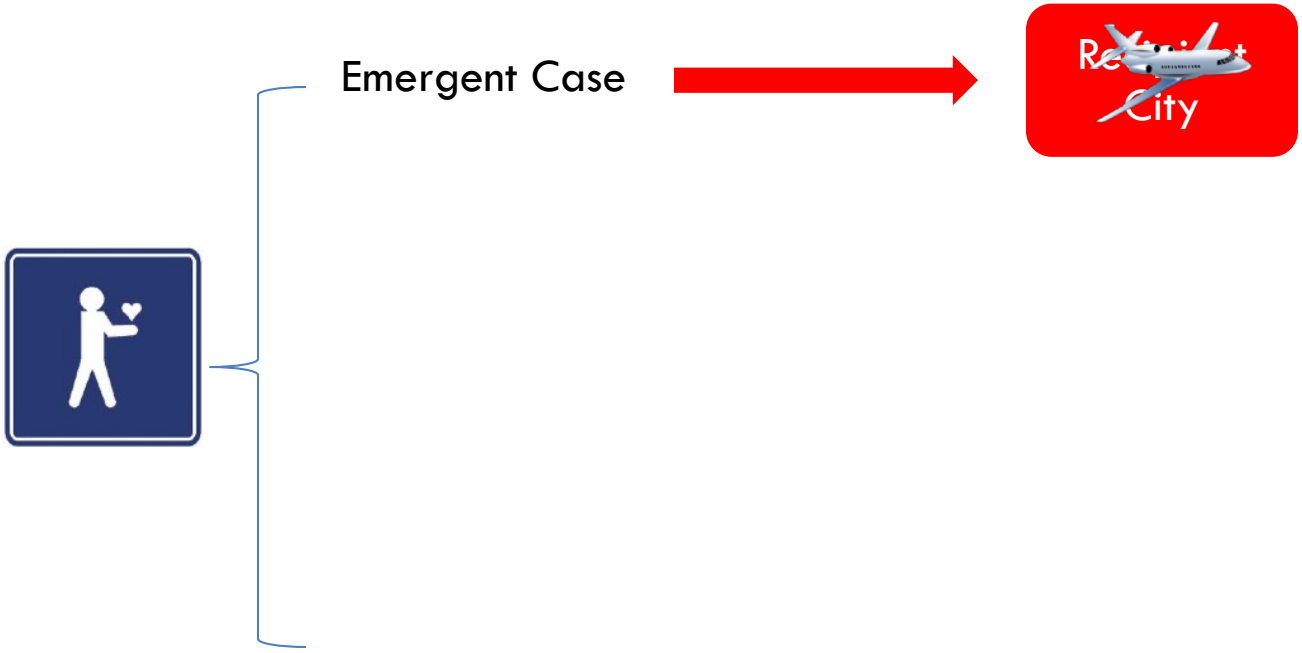
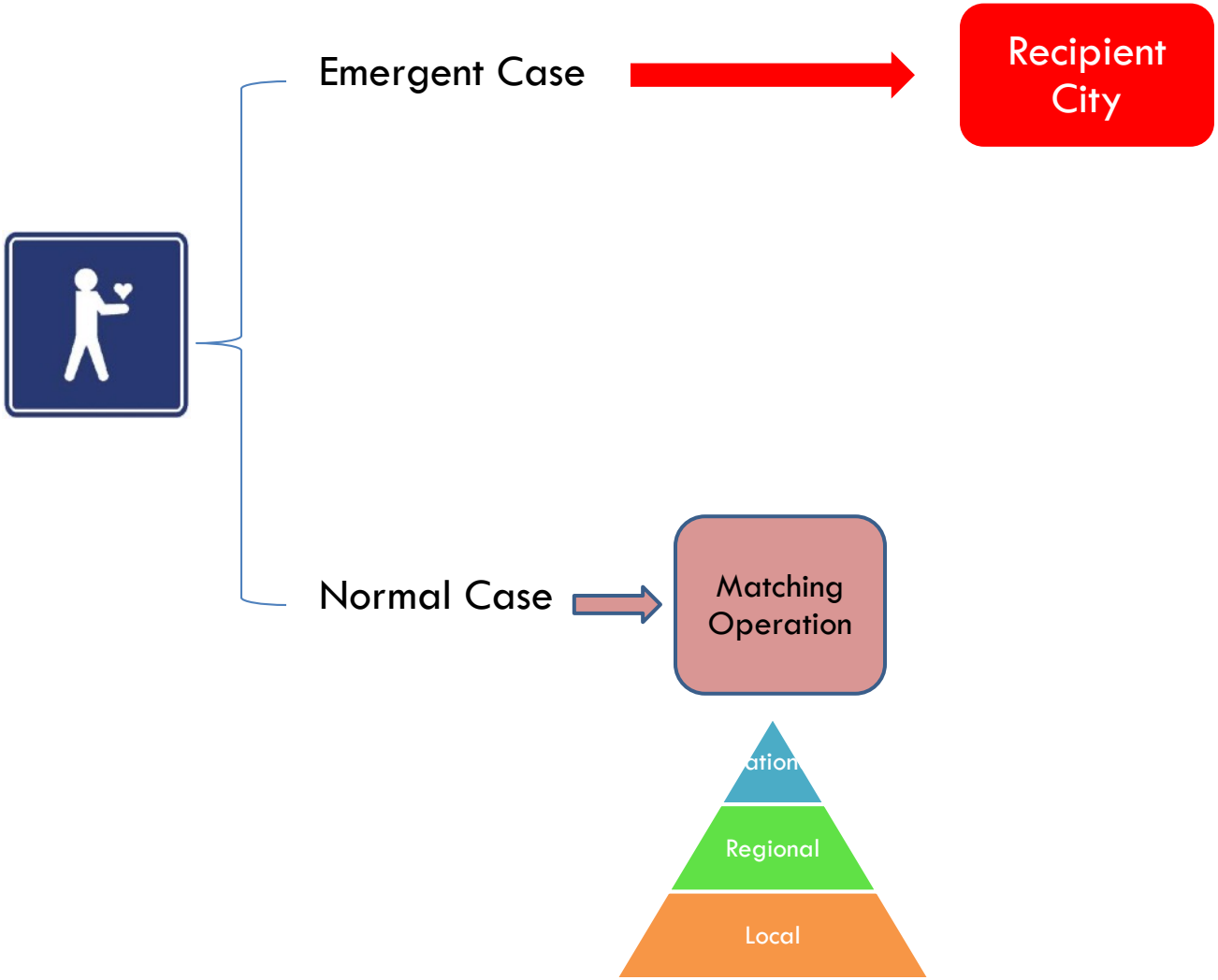


Organ Transplantation Procedure

Emergent Case → Recipient City

Normal Case

Organ Transplantation Procedure



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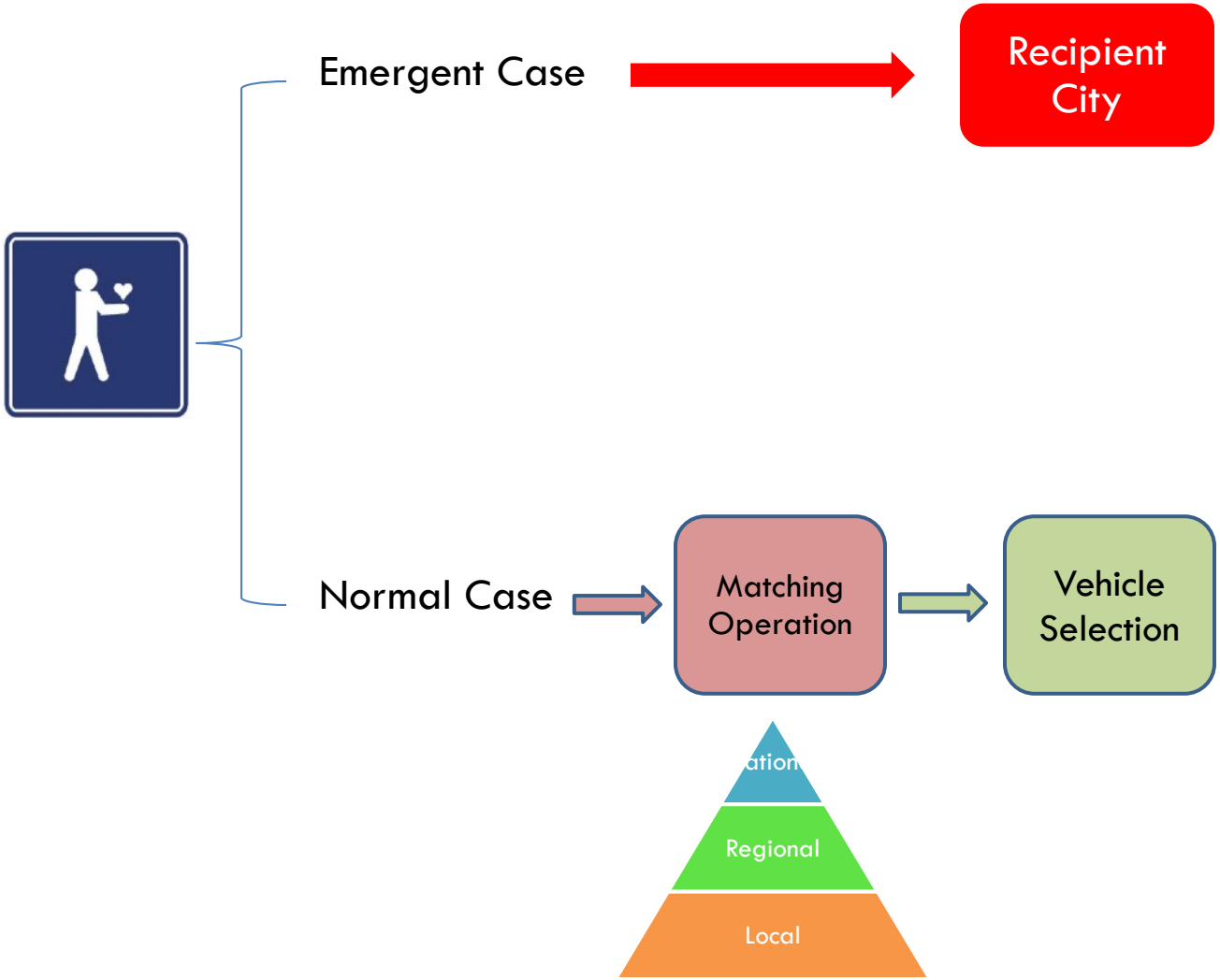
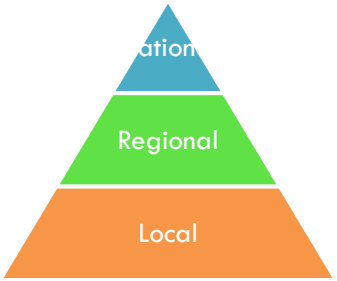


Organ Transplantation Procedure

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

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

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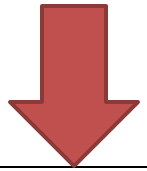

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Problem Definition

- 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)

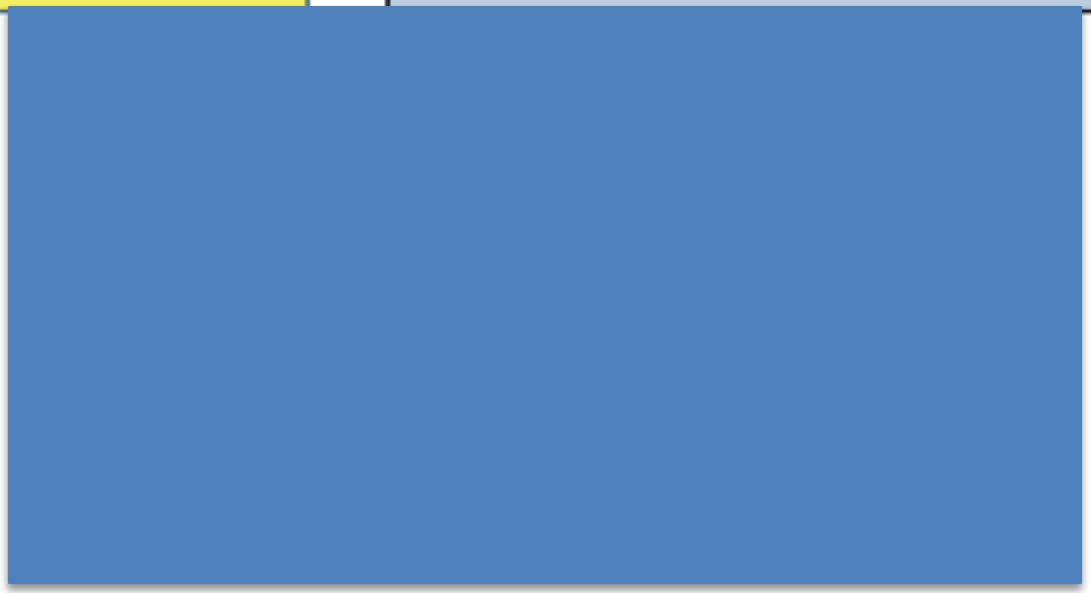
u(i,s): helicopter travel time between nodes

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)



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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 1

Model 1

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

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

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

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Model 2

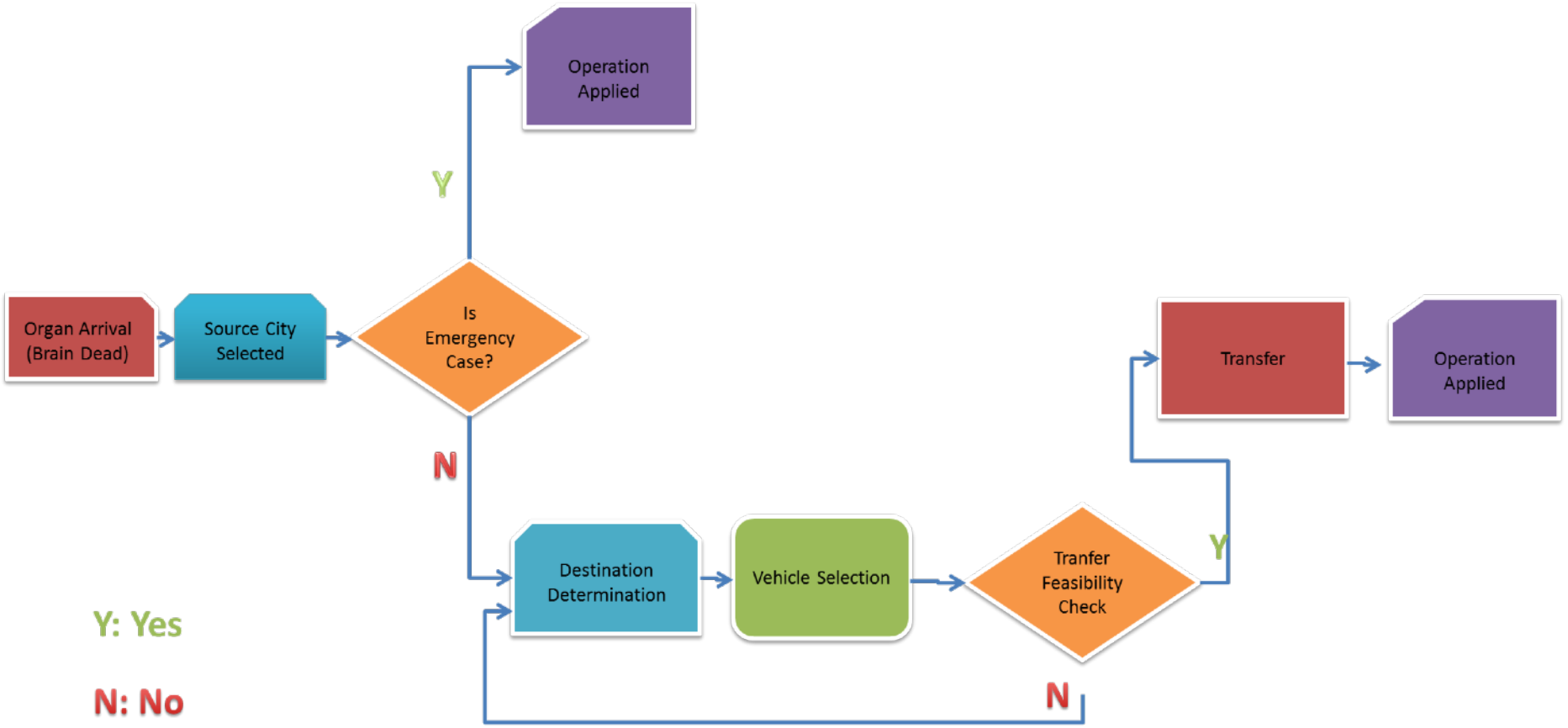
$$\max \sum_{i,j,k} O_i d_j y_{ij}^k$$

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

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

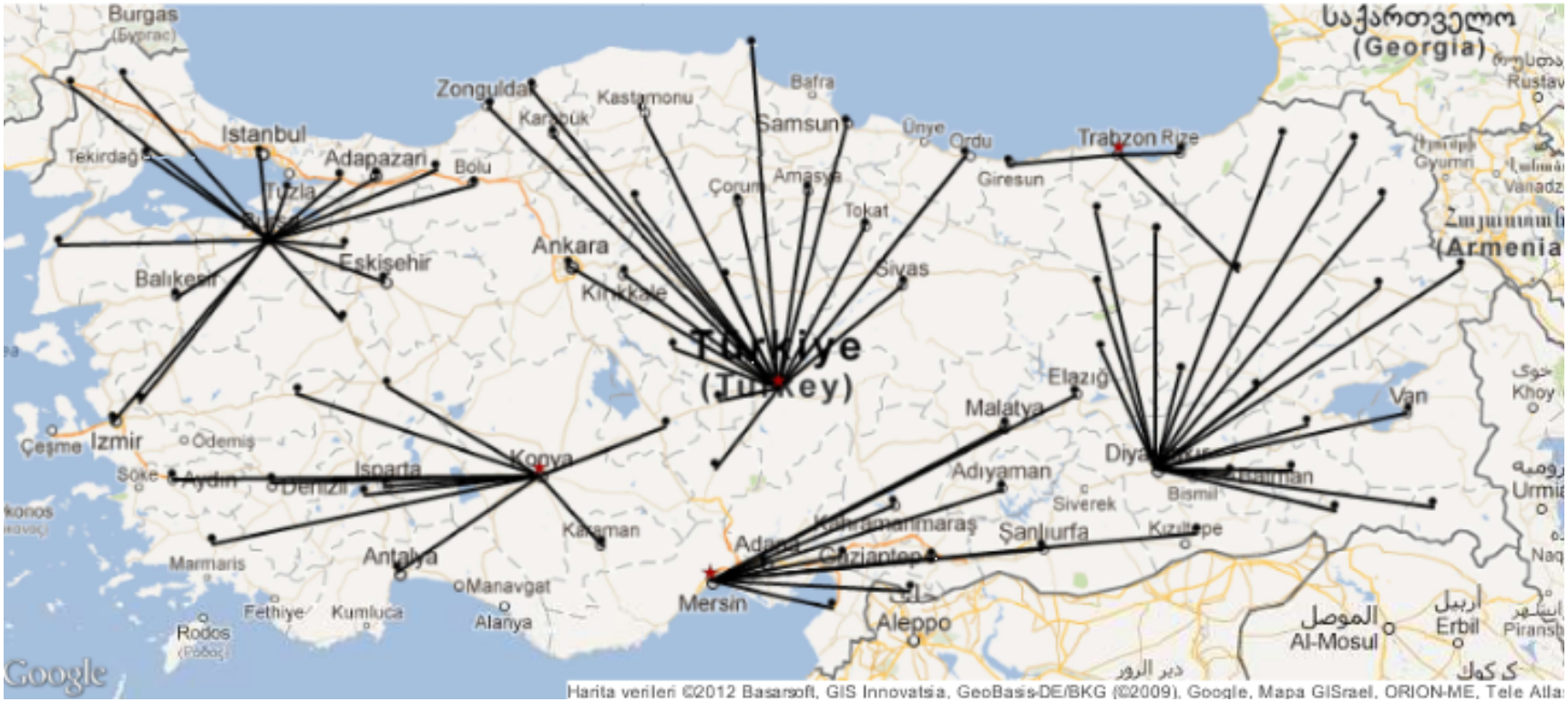
Donated Organ	Donation Percentage
Kidney	76,5 %
Liver	20,2 %
Heart	3,3 %

- 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



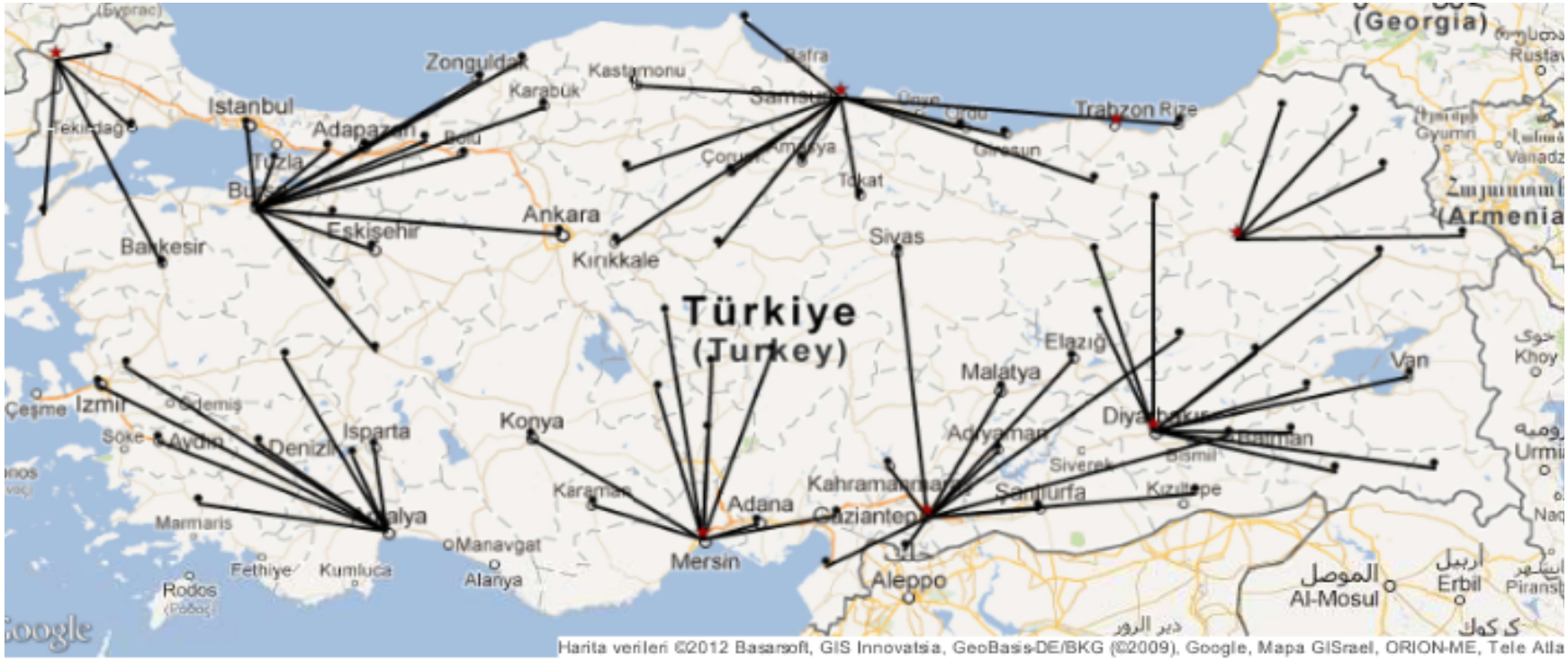
Model 1 Results

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

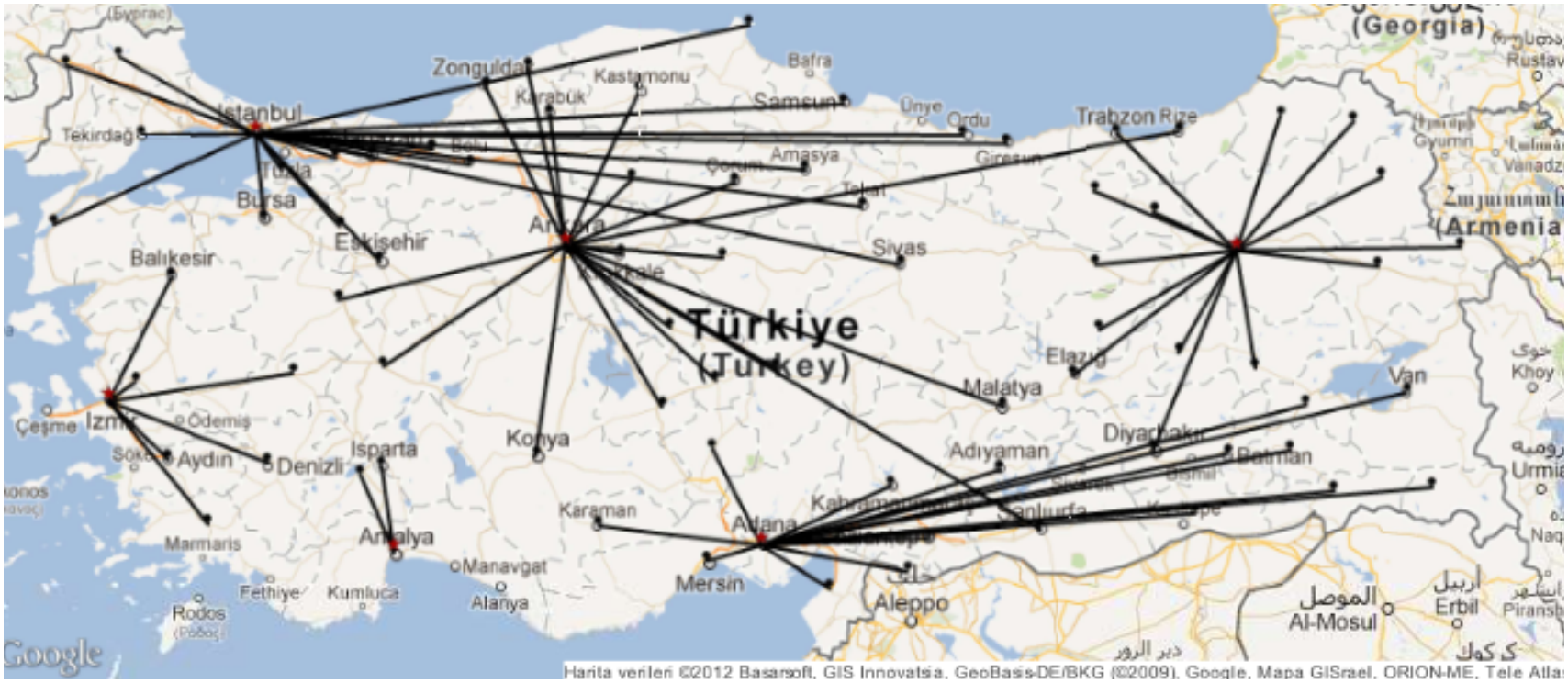


Model 2 Solutions

- 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)

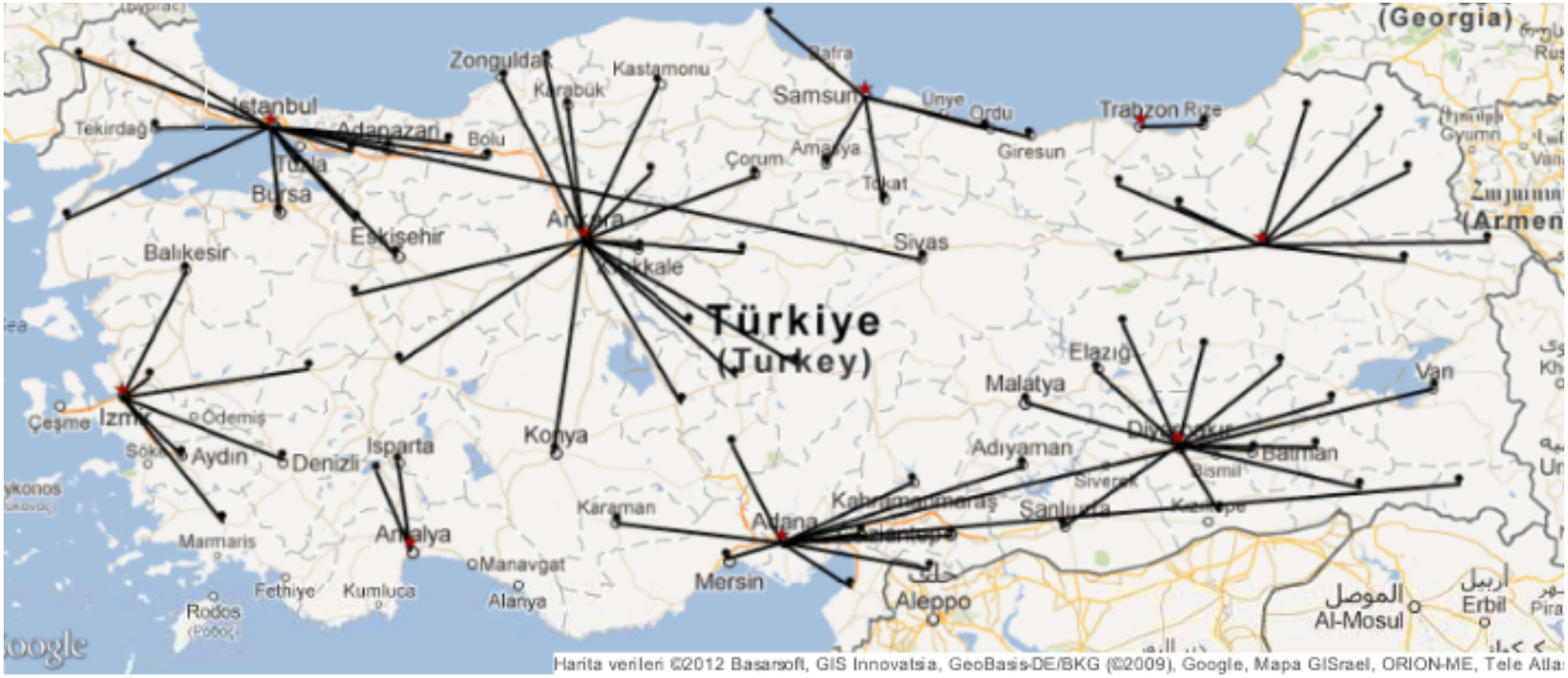
Model 2 Solution

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

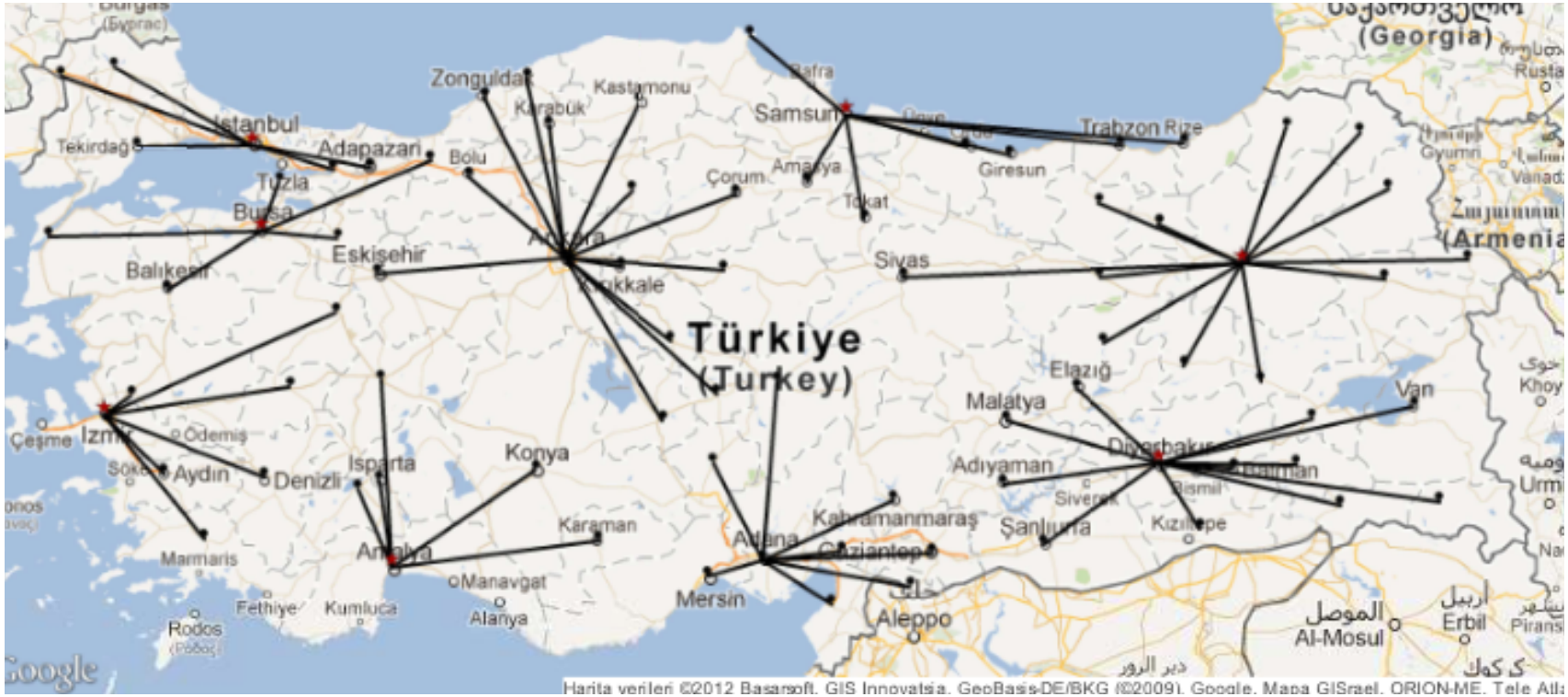


Model 2 Solution

- 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 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 % ↑

Current System vs. Proposed System

Current System vs. Proposed System

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

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

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- Model 2 based outcomes p=9, T=220

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- Proposed: 92% , helikopter usage 17 times with 3 helicopters

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- 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