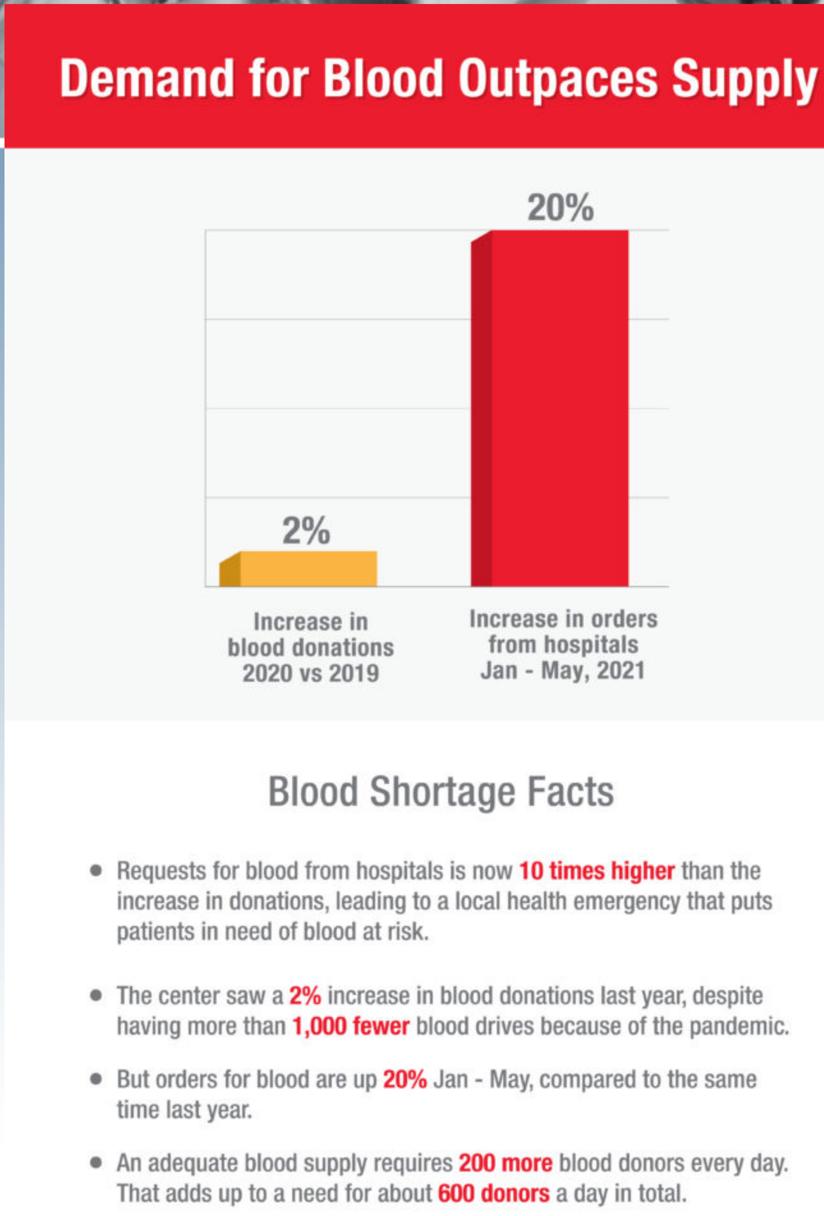
Mobile Blood Donation Logistics:
Case for Turkish Red Crescent

Şahinyazan, Feyza Güliz, Bahar Y. Kara, and Mehme
Rüştü Taner. "Selective vehicle routing for a mobile
blood donation system." *European Journal o*
Operational Research 245.1 (2015): 22-34.

Blood Donation

- Blood has a continuous demand.
  - Accidents, organ transplantations
  - Cancer patients (Regular transfusion)
- Blood is a non-producable product.
- Only source of blood is other human beings.



Blood Donation

- Blood can be collected in the forms of
  - Centrifuge
    - Whole blood
  - Apheresis
    - Platelets
    - Erythrocytes (Red Blood Cells)
    - Plasma

Blood Donation

- Centrifuge
  - Easy for both the donor and the collector
  - Can be performed almost everywhere
  - Perishes in 24 hours
- Apheresis
  - More than 1 unit in 1 session
  - Harder for the patient (2.5 hrs)
  - Not portable
  - Needs specialized facilities

Blood Logistics

- Blood Donation Logistics: Red Crosses and Red Crescents
  - <u>Voluntary Blood Donation: </u>*Blood donation without asking for any benefit from it.*
  - *People around the world continue to sell their blood. Consequences concerned by World Health Organization (WHO)*

Blood Logistics

- Consequences of selling blood:
  - *Tests may not be accurate*
  - *Sellers lie about their physical conditions*
  - *Diseases may spread quickly*
  - *Receiver’s medical condition get even worse*

Blood Logistics

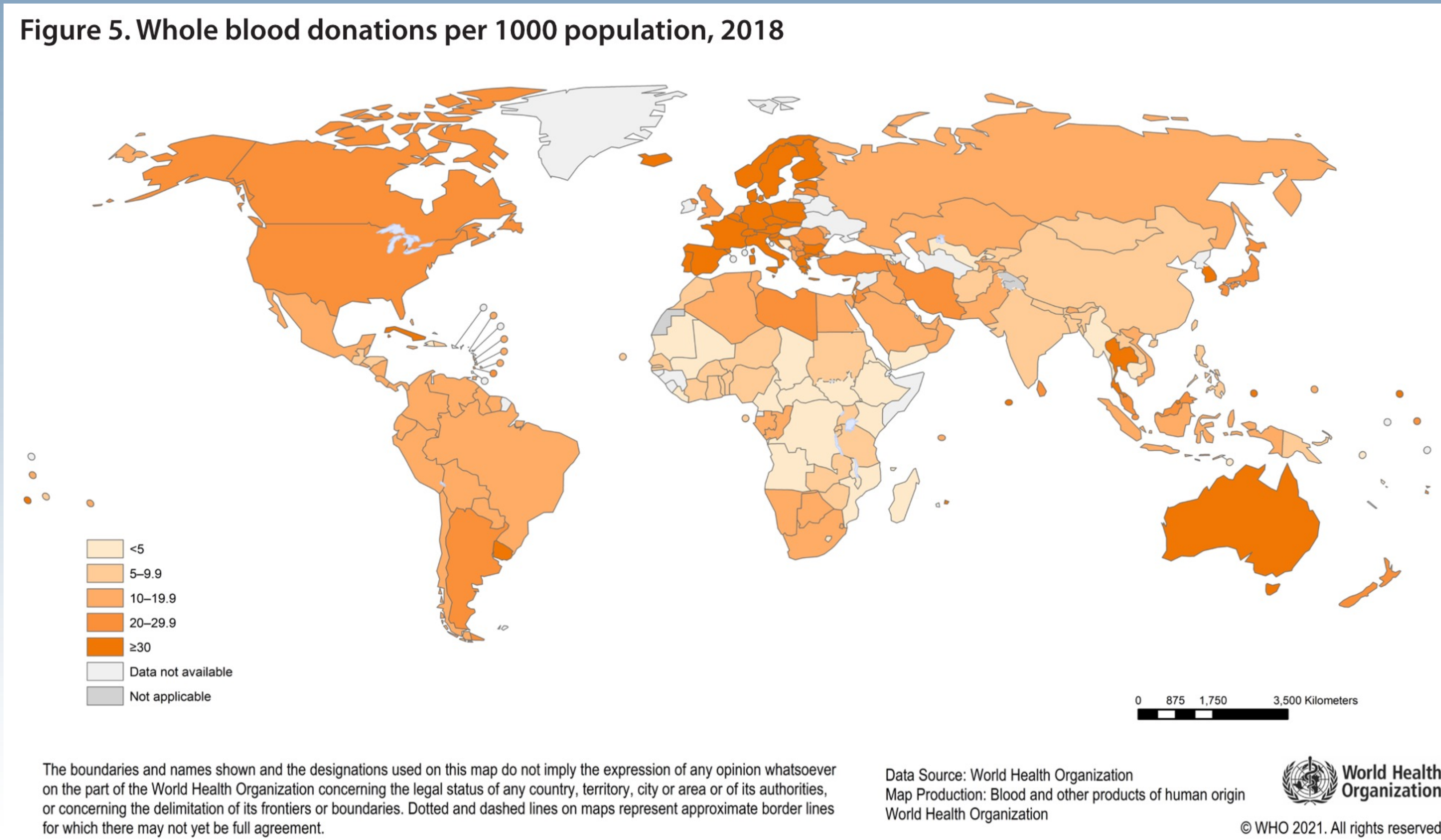


Figure 1. Blood donation amounts

Blood Logistics

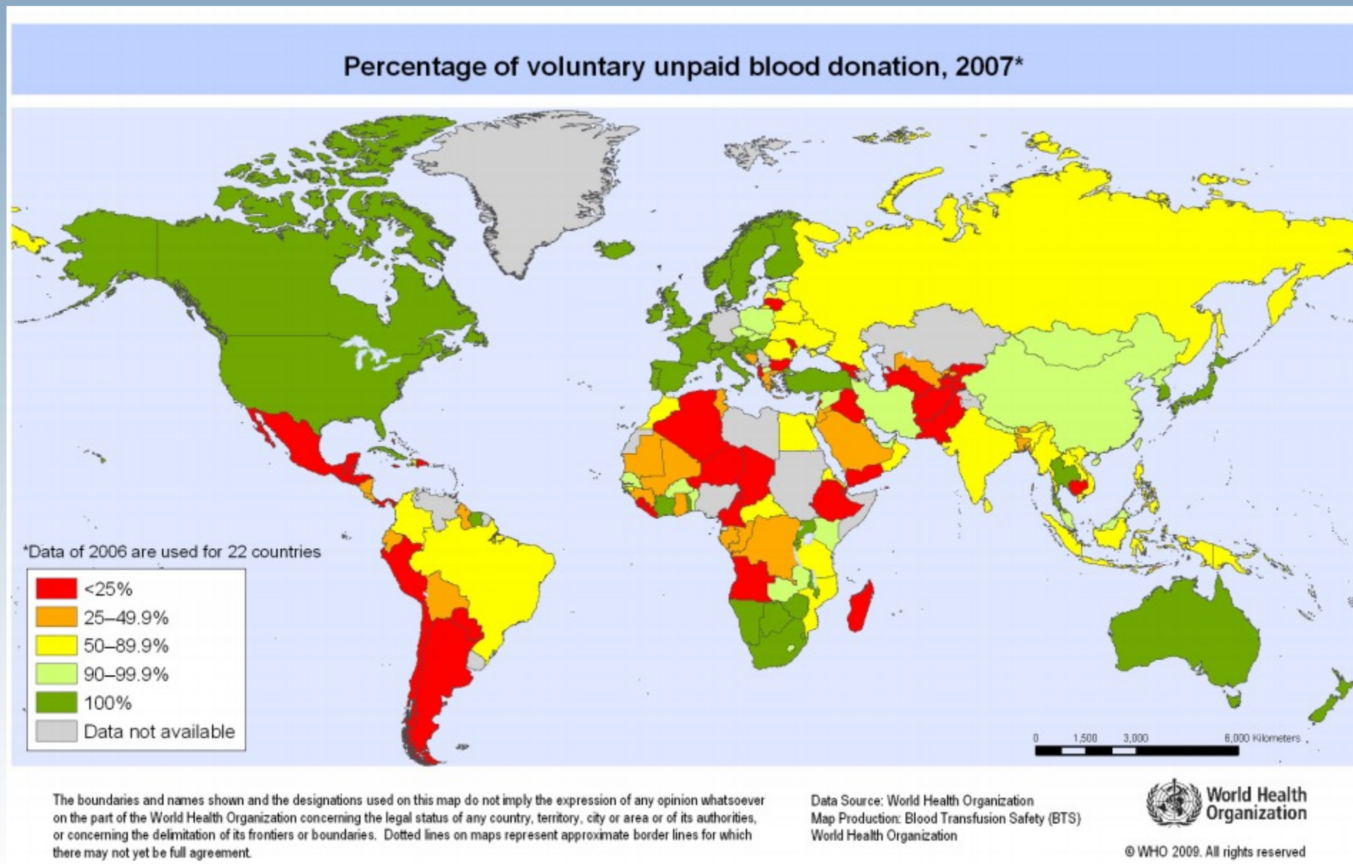


Figure 2. Percentage of voluntary blood donation

Blood Logistics

- Around the world:
  - *5% of the population are regular blood donors.*
  - *81 million units of blood is in need per year.*
    - *82% of this amount is donated in developed countries, under right circumstances and transfused after analysis.*

Blood Logistics

- *USA:* almost 10 million units of blood, %50 is collected by ARC.
  - ~80% of donation via **mobile units**

- *Germany:* almost 4,2 million units of blood, %85 is from volunteered donors.

- *Japan:* almost 4 million units of blood, %100 is from volunteered donors.

Blood Logistics

In Turkey:

- Volunteered blood donation : 1,5-2% of the population.
- TRC is able to meet the demand in 35 % with volunteered blood donation.
- Only 5% is collected by mobile units.

Blood Logistics

Blood collection takes place in:

- Turkish Red Crescent (TRC)
- Hospitals (on demand)
  - Not centralized
    - Blood availability /excess in different facilities (Blood types)
    - Difficulties: Patient’s family

Blood Logistics

TRC collects blood via:

- Fixed Units
- Mobile Units

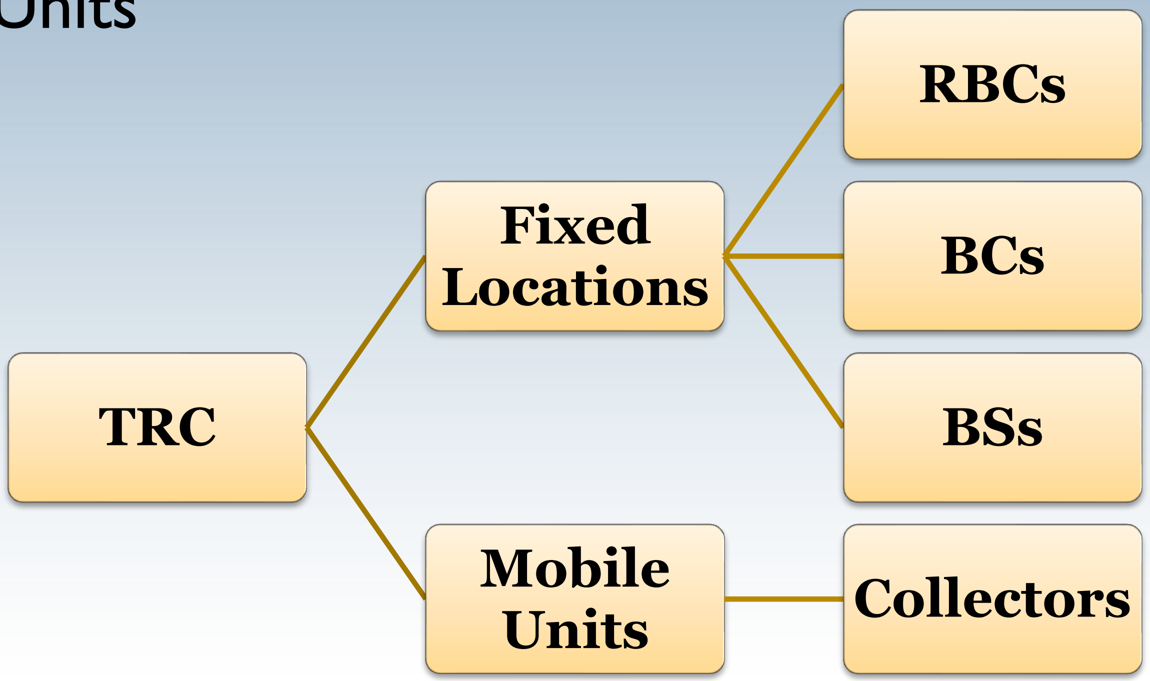


Figure 3. Components of TRC

Blood Logistics

- Fixed Points
  - **R**egional **B**lood **C**enters
    - *Centers with developed opportunities*
  - **B**lood **C**enters
    - *Centers with* ***less*** *developed opportunities, but more common*
  - **B**lood **S**tations
    - *Supporting Facilities for Collection and Temporary Storage*

Blood Logistics

- Mobile Units:
  - Consist of bloodmobiles.
    - **Bloodmobile:** A vehicle containing necessary equipment for the blood donation procedure.
  - Effective if constructed well
  - Reach people who has no time/transportation
  - The collected blood needs to be sent to the closest RBC/BC for analysis and storage within a maximum of 24 hours after its collection

Blood Logistics

Current System:

- Bloodmobiles perform ***dedicated*** tours to ***certain*** activities. (College fests, fairs, etc.)
- Needs to turn the depot in 24 hrs.
- Serves as a portable blood center rather than a mobile unit with regular tours.

Problem Definition

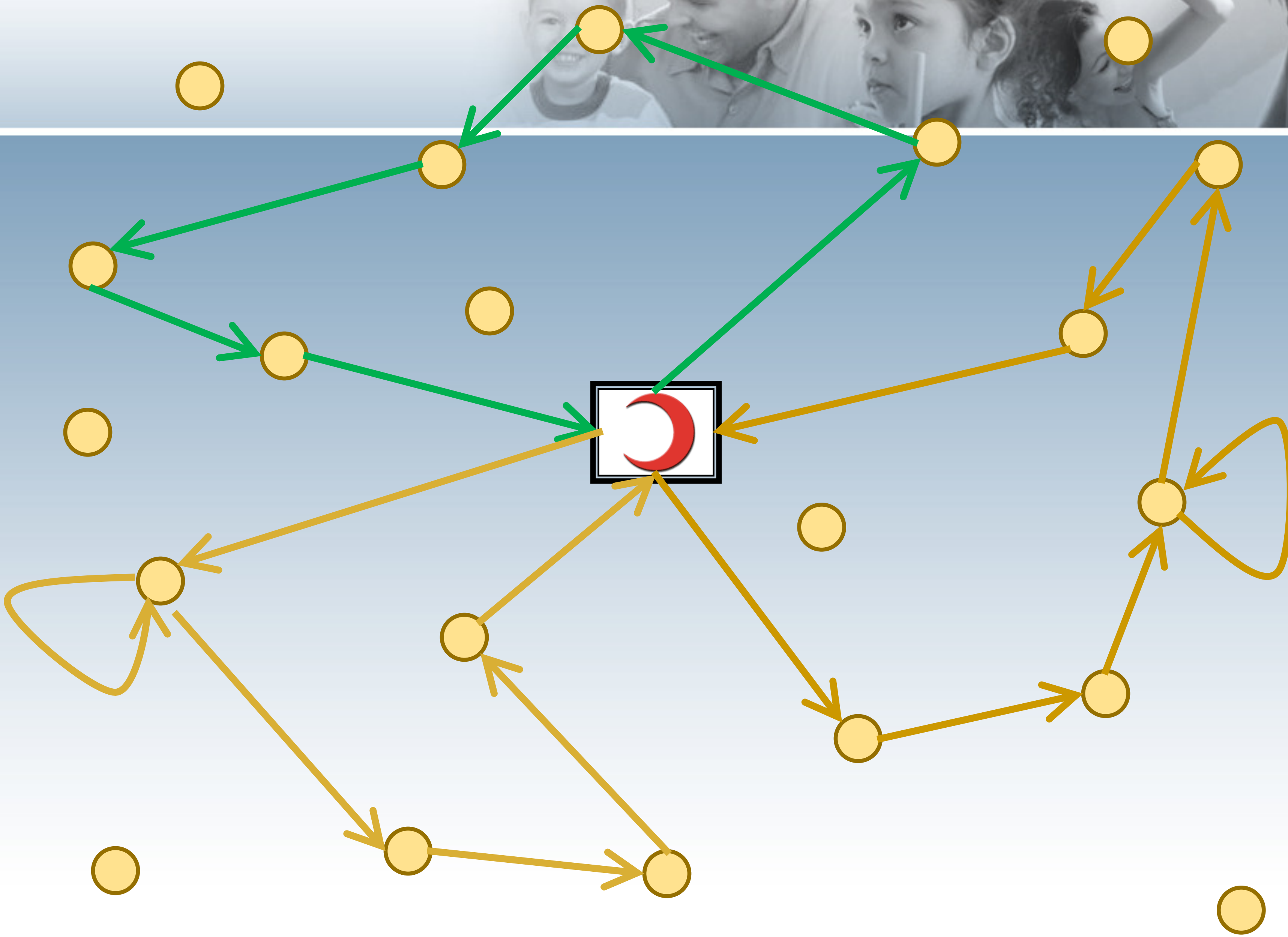
Design of a new mobile system for TRC which:

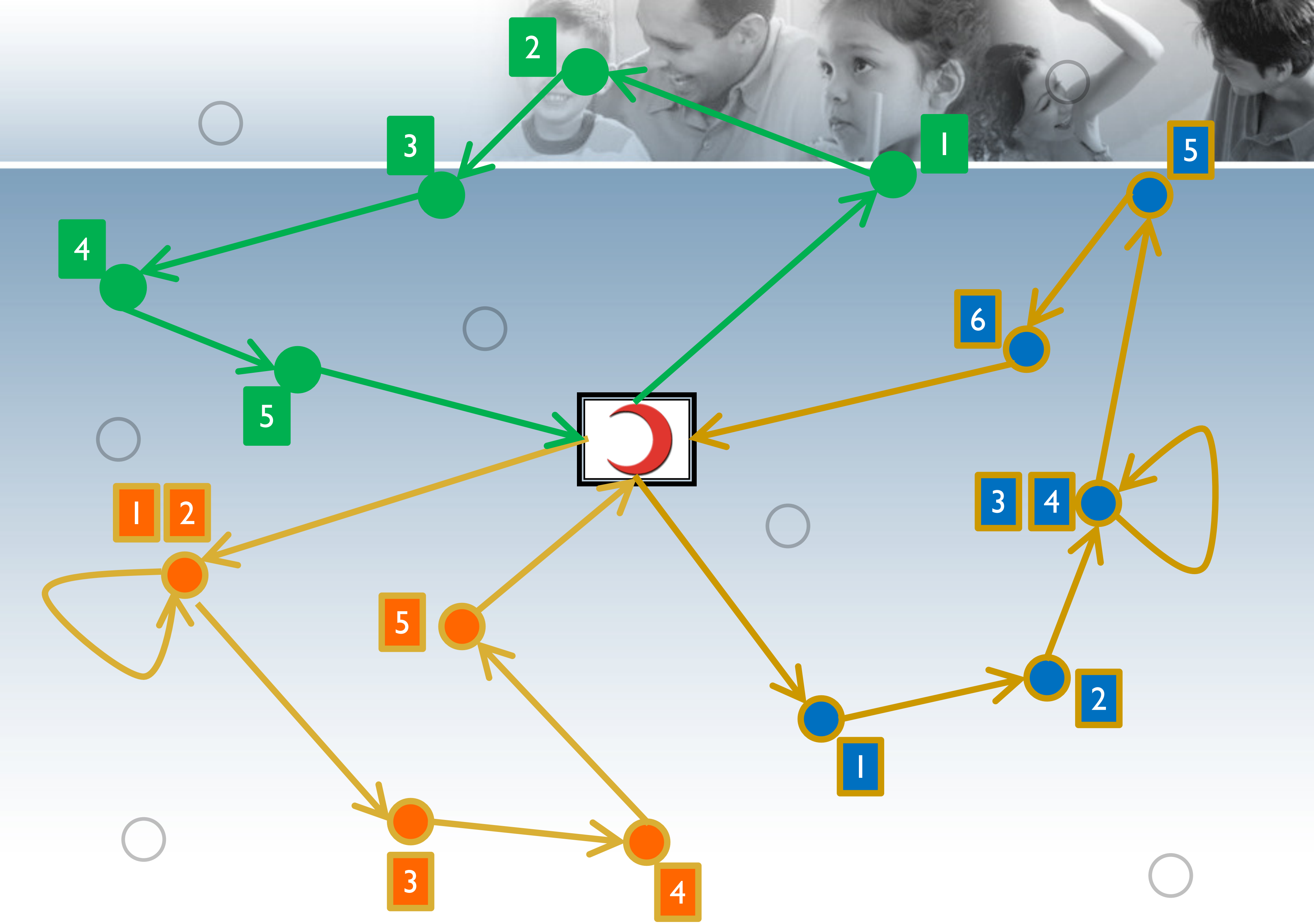
- Maximizes the blood collected
- Minimizes the blood collection costs,
- *Allows bloodmobiles to stay more than one day at the same location.*

Problem Definition

In the ***proposed*** system mobile units consist of,

- Collector vehicles (Bloodmobiles):
  - Where blood donation takes place
  - Appropriate short-term storage (24 hrs)
- Shuttle:
  - Collection and transportation of blood between collectors and RBC/BC's at the end of each collection day




2
3
1
5
4
6
5
3
4
1
2
5
2
1
3
4

2

1

3

5

4

6

5

3 4

1 2

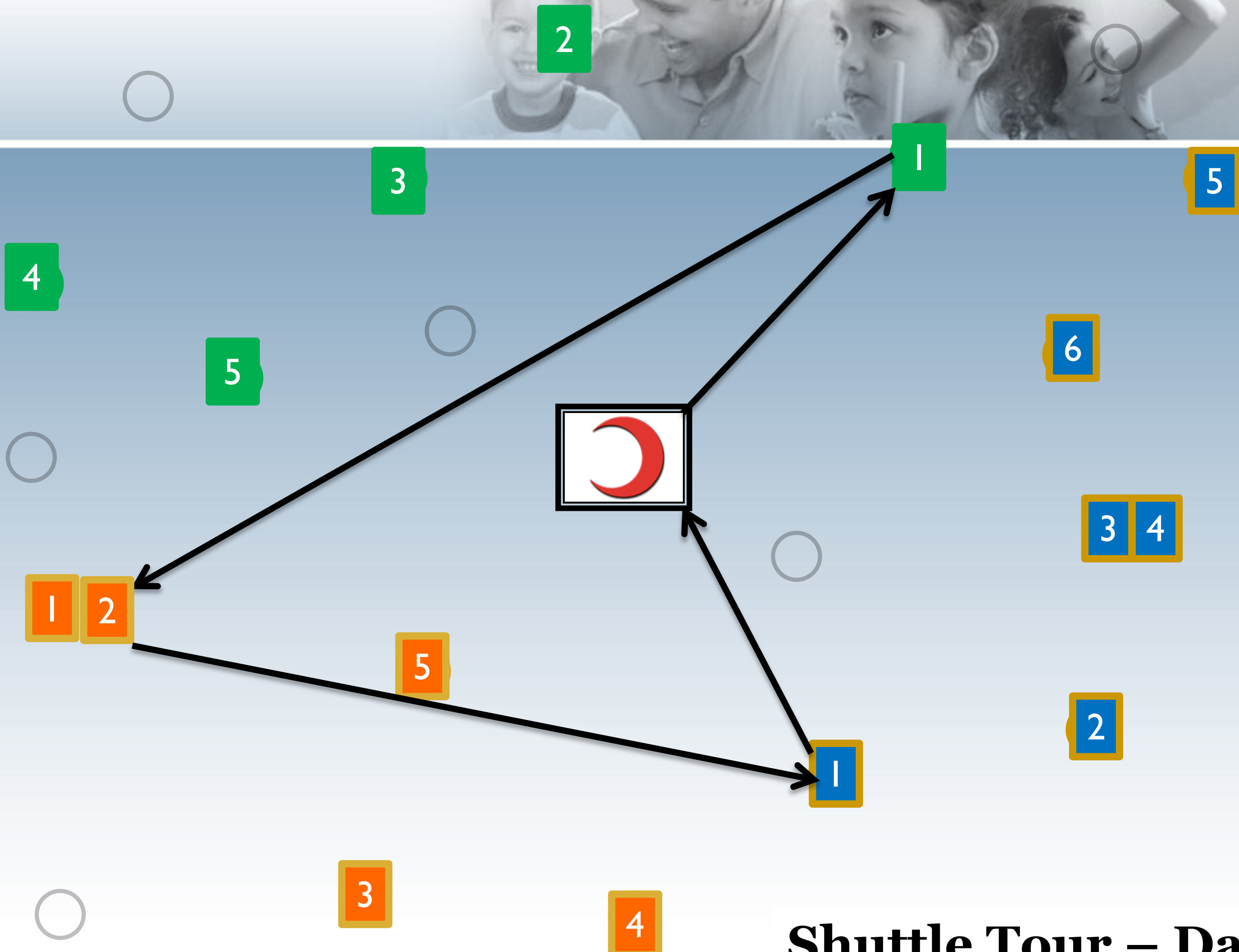
5

2

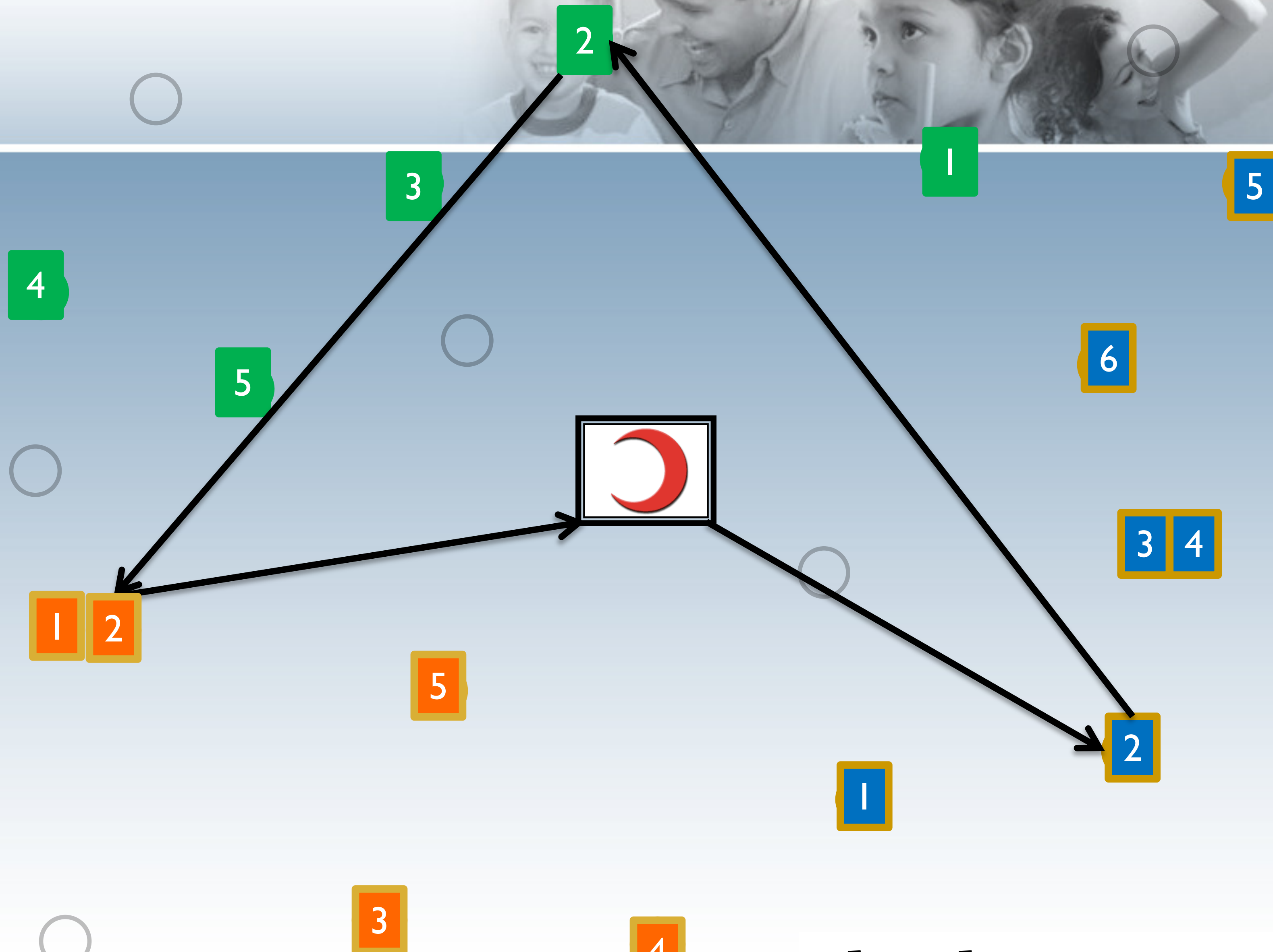
1

3

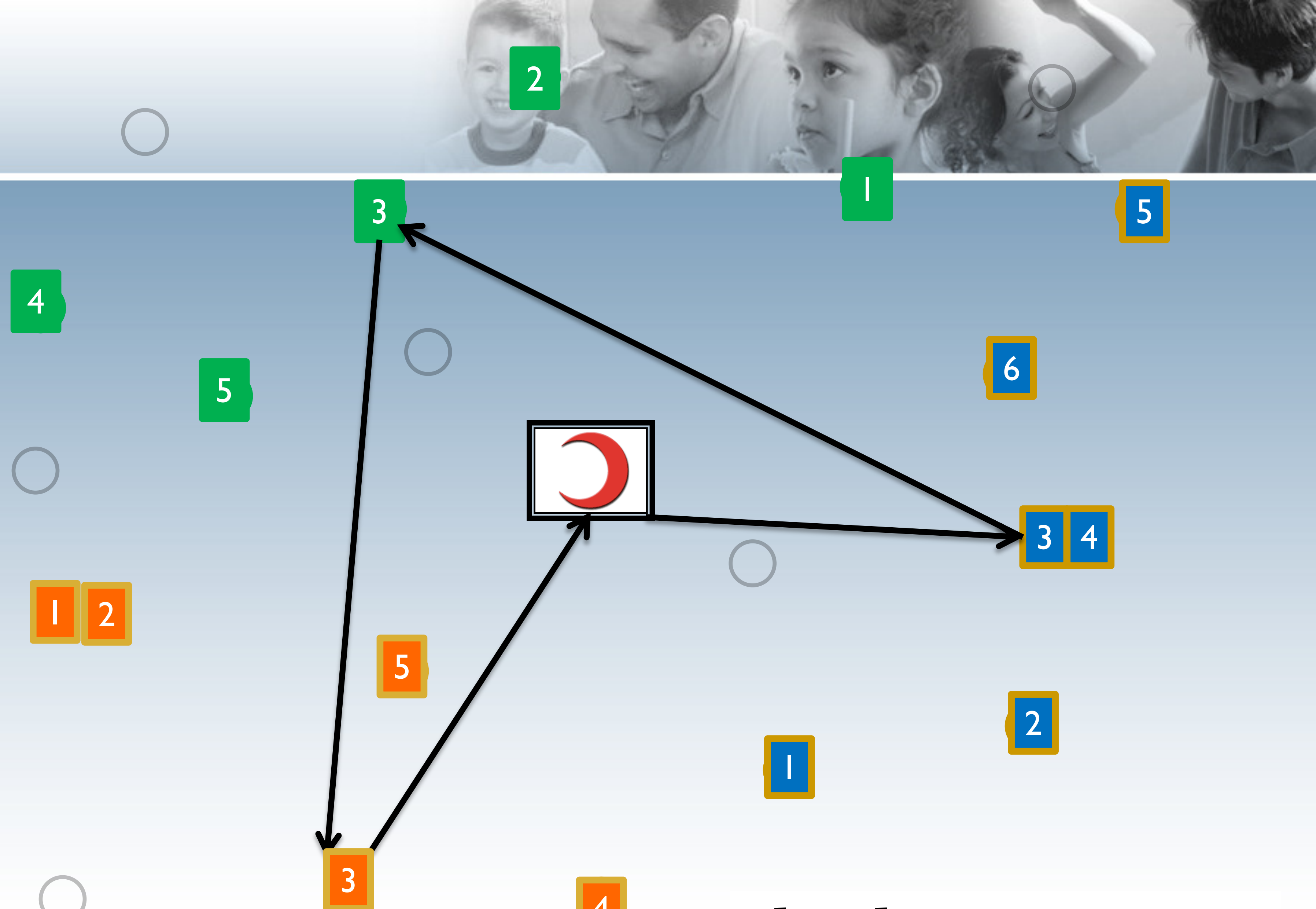
4



Shuttle Tour – Day 1



Shuttle Tour – Day 2



Shuttle Tour – Day 3

Problem Definition

Decisions to be made simultaneously:

- Stops of the bloodmobiles,
- Length of the stay in a stop,
- Tours of the bloodmobiles,
- Tours of the shuttle.

Problem Definition

Integrated selective tours:

- for Collectors
- for shuttle (Daily TSP tours)

<u>New problem</u>

→ *Selective VRP with Integrated Tours*

Model Development

Bi-criteria :

- Maximizes the blood collected
- Minimizes the blood collection costs

(Min Cost
s.t
“Max” blood)

The possible stay-overs of bloodmobiles

- $G = (N, A)$
- $N \setminus \{1\}$ is the set of potential stops of the bloodmobile
- $\{1\}$ is the given location of the depot
- Set A represents the roads between these nodes

The possible stay-overs of bloodmobiles

- We will use a time-extended version G' of G
- For each actual potential location v, G' has three nodes:
  - the first one is the original node v
  - the artificial nodes v' and v'' corresponding to 2-day and 3-day stay-overs, respectively
  - If a blood mobile visits v' , it means the bloodmobile stays in v for 2 days
  - If a blood mobile visits v'' , it means the bloodmobile stays in v for 3 days
  - G' is designed in a way that v'' and v' cannot be visited unless a bloodmobile visits v

- $G' = (N', A')$
- $|N'| = 3|N|$
- $v_{i+|N|}$ represents 2 day stay overs
- $v_{i+2|N|}$ represents 3 day stay overs

- $c_{i,i+|N|} = c_{i,i+2|N|} = 0$

A decreasing function that represents the blood potential

- **The blood potential decreases on the second day and decreases even more on the third day of the activity**
- Value of blood collected in one day=

$$\beta$$

- Value of blood collected in two days=

$$b_j + b_j\beta$$

- Value of blood collected in three days=

$$b_j + b_j\beta + b_j\beta^2$$

$$b_j = \begin{cases} b_j, & \text{if } j \leq |N| \\ b_j\beta, & \text{if } |N| < j \leq 2|N| \\ b_j\beta^2, & \text{if } j > 2|N| \end{cases}$$

$0 \leq \beta \leq 1$

Model Development

Given the cost matrix and the blood potentials of original nodes, for **copy** nodes,

cost:

$$c'_{i'j'} = c_{ij}, \quad \forall i \equiv i' \left(\mathrm{mod}_{|N|}\right), \quad \forall j \equiv j' \left(\mathrm{mod}_{|N|}\right)$$

Model Development

Parameters:

c'_{ij} = *The travelling cost from node i and to node j, where $(i,j) \in A'$*

b_j = *The blood potential of node j, where $j \in N'$*

B^* = *Desired value for the amount of blood to be collected*

m = *Number of bloodmobiles*

Decision variables:

$$x_{ijd} = \begin{cases} 1, \text{if a bloodmobile travels to node } j \in N' \text{ directly from node } i \in N' \text{ on day } d \in D \\ 0, ow \end{cases}$$

$$y_{ijd} = \begin{cases} 1, \text{if the shuttle travels to node } j \in N' \text{ directly from node } i \in N' \text{ on day } d \in D \\ 0, ow \end{cases}$$

$$z_{id} = \begin{cases} 1, \text{if node } i \in N' \text{ requires a shuttle on day } d \in D \\ 0, ow \end{cases}$$

V_i = *dummy continuous variable that represents the order of node $i \in N'$ in a shuttle tour*

Model Development

(MinCost – st B-Blood)*

$$\text{minimize} \quad \sum_{j\in N'}\sum_{i\in N'} c'_{ij} \sum_{d\in D} X_{ijd} + \sum_{j\in N'}\sum_{i\in N'} c'_{ij} \sum_{d\in D} Y_{ijd}$$

subject to

Bloodmobile const.

$$\sum_{i\in N'} X_{ijd} = Z_{jd} + X_{j1d+1}, \qquad \forall j \in \{2,\dots,N'\}, \forall d \in \{1,\dots,D-1\}$$

$$\sum_{d\in\{1,\dots,D-1\}} (X_{j1d+1} + Z_{jd}) \le 1, \qquad \forall j \in \{2,\dots,N'\}$$

$$\sum_{i\in N'} X_{ijd} = \sum_{k\in N'} X_{jkd+1}, \qquad \forall j \in \{2,\dots,N'\}, \forall d \in \{1,\dots,D-1\}$$

$$\sum_{i\in N'} X_{ijd} \ge X_{j(j+|N|)(d+1)}, \forall j \in \{1,\dots,2|N|\}, \forall d \in \{1,\dots,D-1\}$$

$$X_{(j-N)jd} \ge Z_{jd} + X_{j1d+1}, \forall j \in \{|N|+1,\dots 3|N|\}, \forall d \in \{1,\dots,D-1\}$$

$$\sum_{j\in N'} \sum_{i\in\{2,\dots,N'\}} X_{ij1} = 0$$

Model Development

(MinCost-B-Blood) –Shuttle const.*

Shuttle constraints

$$\sum_{i \in N'} Y_{ijd} = Z_{jd}, \qquad \forall j \in N', \forall d \in \{1, \ldots, D-1\}$$

$$\sum_{i \in N'} Y_{jid} = Z_{jd}, \qquad \forall j \in N', \forall d \in \{1, \ldots, D-1\}$$

$$\sum_{j \in \{2,\ldots,N\}} Z_{jd} \leq m \sum_{j \in \{2,\ldots,N\}} Y_{1jd}, \qquad \forall d \in \{1, \ldots, D-1\}$$

$$\sum_{j \in \{2,\ldots,N\}} Z_{jd} \leq m \sum_{j \in \{2,\ldots,N\}} Y_{j1d}, \qquad \forall d \in \{1, \ldots, D-1\}$$

$$V_i - V_j + mY_{ijd} \leq m - 1, \forall j \in \{2, \ldots, N'\}, \forall i \in \{1, \ldots, N'\}, \forall d \in \{1, \ldots, D\}$$

$$V_i \geq 0, \qquad \forall j \in \{2, \ldots, N'\},$$

Model Development

Depot constraints

$$\sum_{j \in N'} X_{1j1} = m$$

$$\sum_{j \in N'} \sum_{d \in D} X_{ijd} = m$$

$$\sum_{j \in N'} b_j \sum_{i \in N'} \sum_{d \in D} X_{ijd} \geq B^*$$

$$X_{ijd}, Y_{ijd}, Z_{jd} \in \{0,1\} \quad \forall d \in \{1, \dots, D\}, \forall j \in \{1, \dots, N'\}, \forall i \in \{1, \dots, N'\}$$

Model Development

MaxBlood model:

$$\text{maximize} \sum_{j \in N'} b_j \sum_{i \in N'} \sum_{d \in \{1,\ldots,|D|-1\}} \left(X_{ijd}\right)$$

subject to

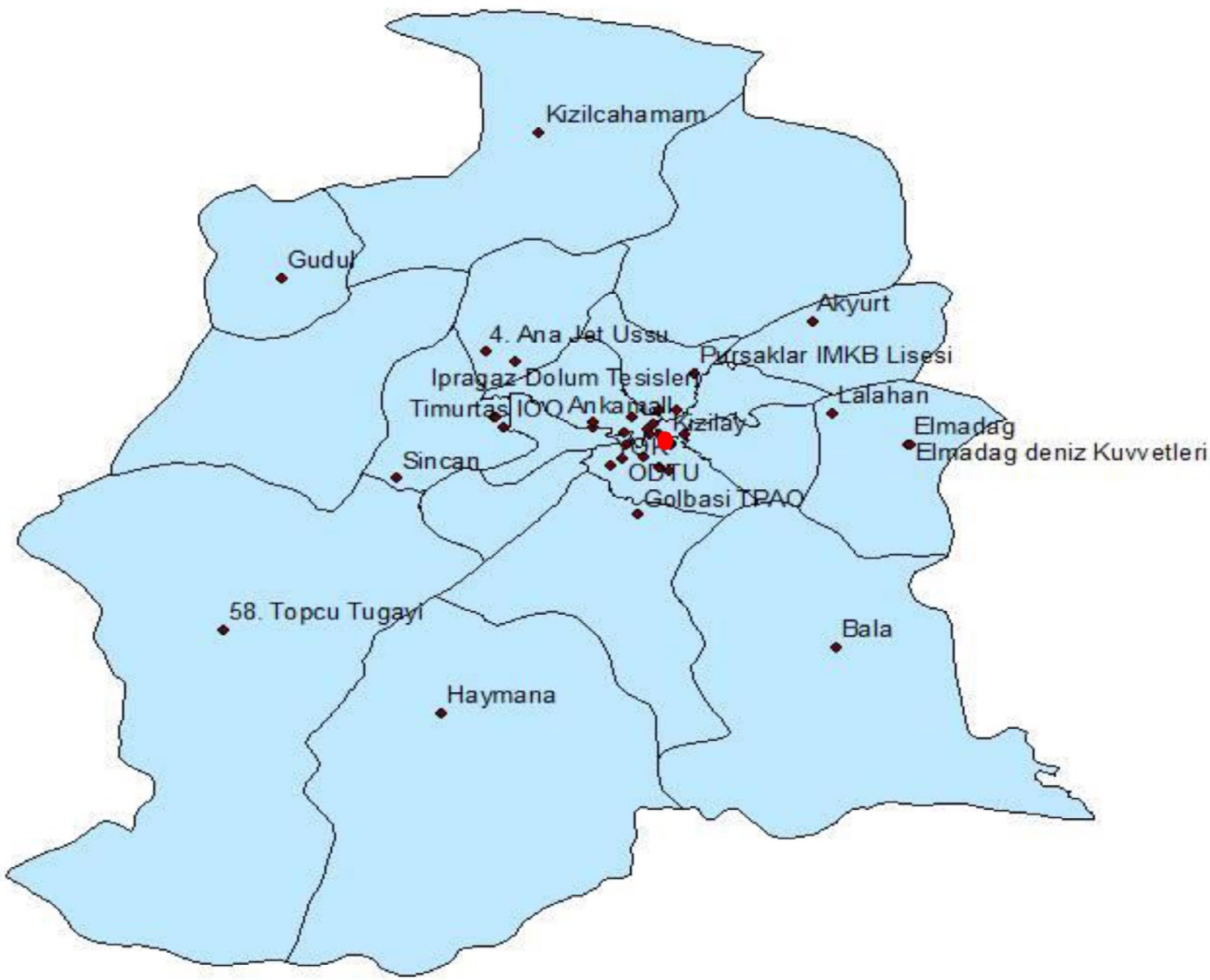
Bloodmobile const's of

MinCost-B-Blood*

Computational Results

- Ankara Case:
  - Based on real collection activity data
  - 38 potential points, 1 depot (TRC Center in Kızılay, an RBC)
  - $|N'| = 117$, t=3, D=8, m=3, β = 0.8

Computational Results



Computational Results

- Ankara Case:

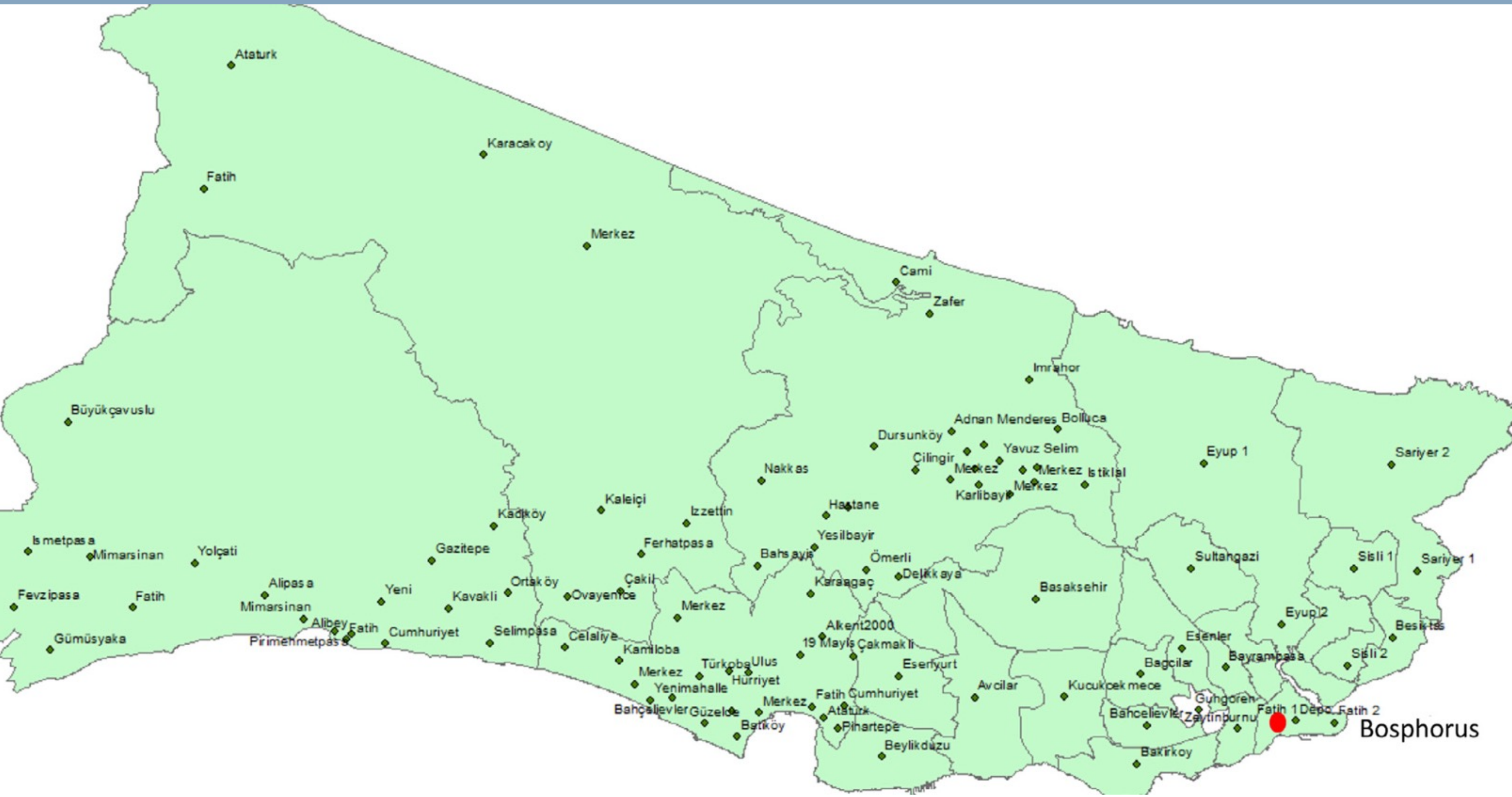
	objective	cpu	node	iteration	shuttle dist	bloodmobile dist
MaxBlood	1420(units)	34 sec	0	27852		
MinCost-B^*-Blood	**912.5 (km)**	212 sec	410	63266	456.6 (km)	455.9 (km)

If this amount were collected by dedicated tours: ***1011*** km.s

Computational Results

- Istanbul Case:
  - Hypothetical data based on GIS
  - population ≈ blood potential
  - 96 potential points, 1 depot (TRC Center in Fatih, a BC)

Computational Results



Computational Results

- Istanbul Case:

	objective	cpu	node	iteration	shuttle dist	bloodmobile dist
MaxBlood	9004079(people)	207 sec	0	62551		
MinCost-B^*-Blood	**446.613(km)**	2083 sec	2228	138757	304.096 (km)	142.517 (km)

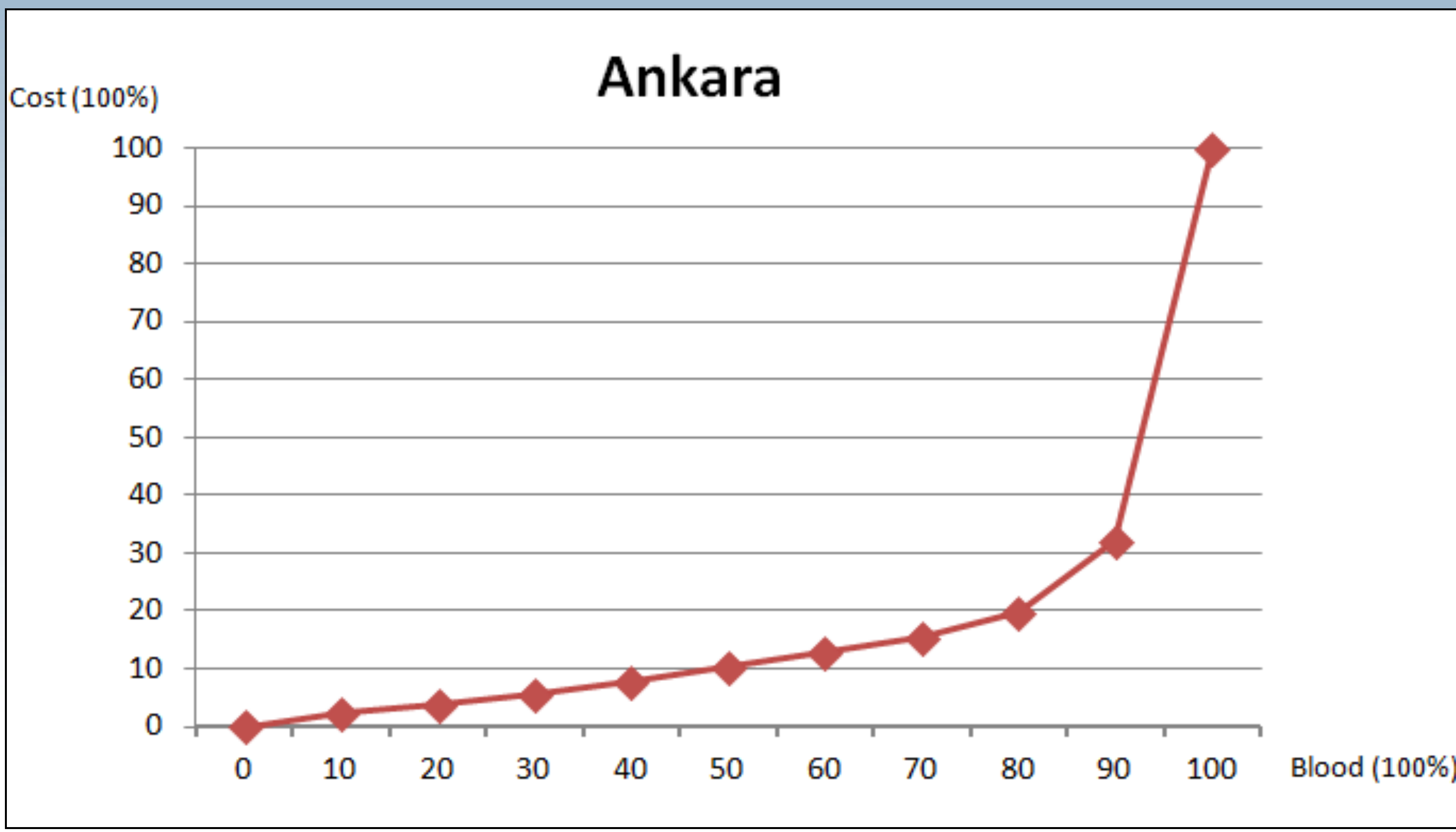
If this amount were collected by dedicated tours: ***661.6*** km.s

Computational Analysis

- Two objectives under consideration
  - Maximizing collected blood
  - Minimizing logistics cost
- Pareto Efficient Curve is developed
  - *MinCost-B*-Blood* is solved for 0.1 increments of optimum solution of *MaxBlood.*

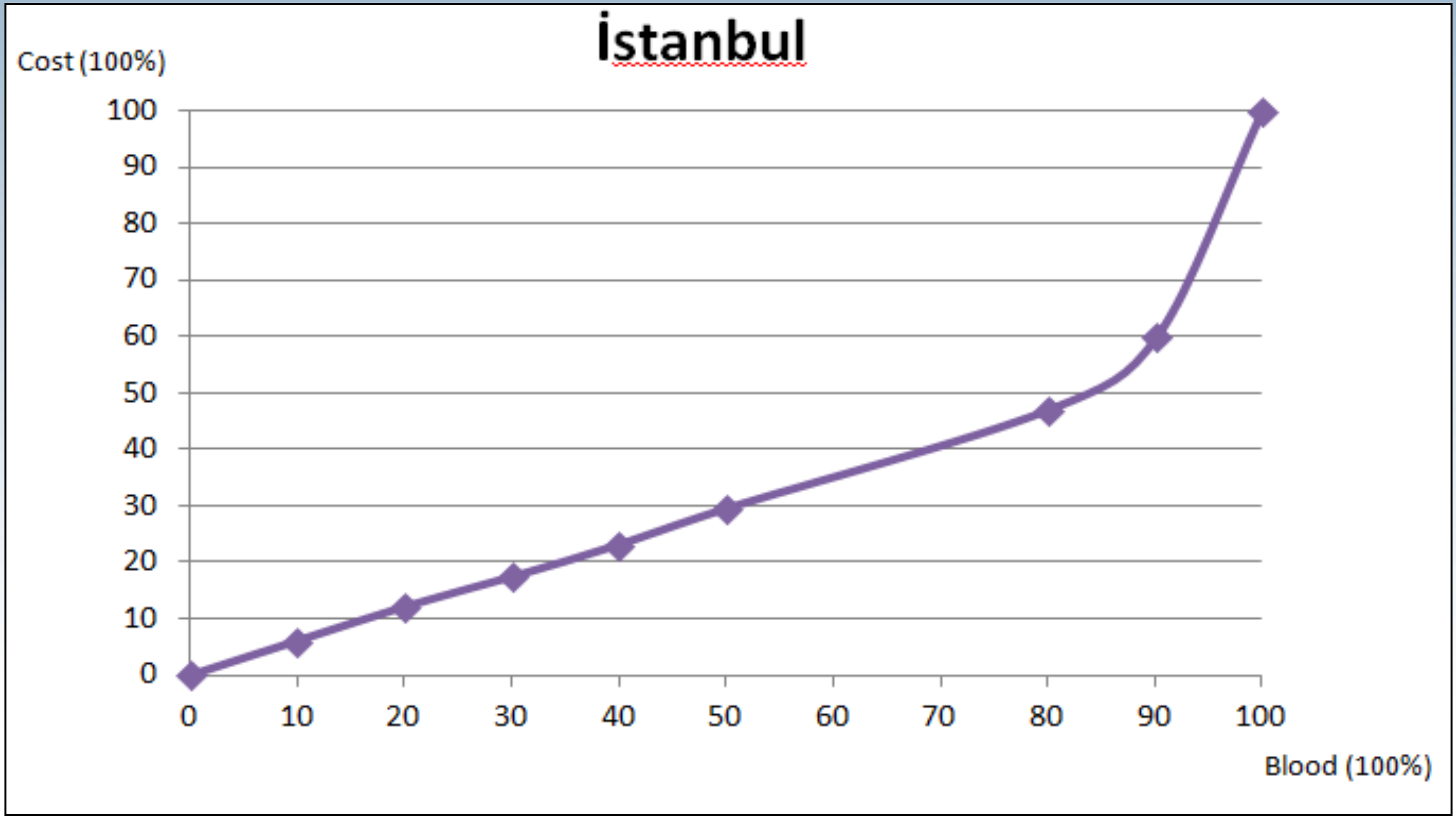
Computational Analysis

- Ankara case:



Computational Analysis

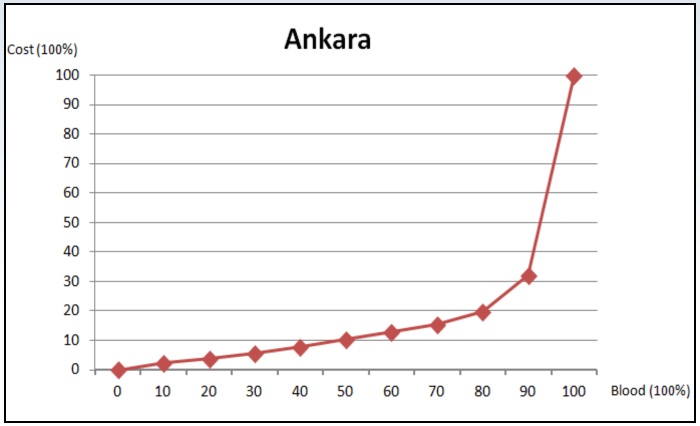
- Istanbul case:

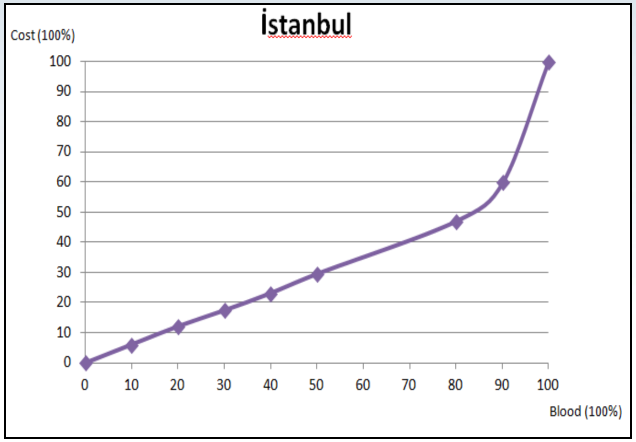


Computational Analysis

- In both cases if TRC settles for the 90% of max. amount of blood logistics costs decrease dramatically.
- Decrease for Ankara is steeper than Istanbul.

→ Different metropolitan structures.





Computational Analysis

- Sensitivity Analysis on *m* and *β*

β	# veh	MaxBlood	marg. inc(%)	MinCost	marg. inc(%)	# nodes stayed in 2 days	# nodes stayed in 3 days	CPU sec(GAP)	dist/ blood
0.2	3	1114	0	1138.7	0	1	0	2222	1.02
	4	1289	15.71	1320	15.92	1	0	36000(8.61%)	1.02
	5	1419	27.38	1599	40.42	2	0	36000(11.7%)	1.13
0.4	3	1151	0	1138.7	0	1	0	2182	0.99
	4	1348	17.12	1355.7	19.05	3	1	36000(4.11%)	1.01
	5	1509	31.1	1399.4	22.89	5	1	36000(6.92%)	0.93
0.6	3	1253	0	855.8	0	3	1	1128	0.68
	4	1483	18.36	1220.5	42.61	6	1	15350	0.82
	5	1679	34	1551.1	81.24	8	3	18945	0.92
0.8	3	1419	0	912.5	0	2	4	186	0.64
	4	1697	19.58	1056.1	15.73	3	5	1135	0.62
	5	1945	36.97	1556.2	70.54	5	6	9453	0.80
1	3	1690	0	714.8	0	0	6	186	0.42
	4	2025	19.82	1152.5	61.23	0	8	298	0.57
	5	2322	37.4	1209.4	69.19	0	10	448	0.52

Computational Analysis

- 3 vehicles are justified for most of the cases. (in terms of cost per unit blood)
- Harder to solve when β decreases.
- Keeping β value high is very important.

TRC can control β with effective campaigns and announcements.

Thank you for your attention!
Any questions / comments?