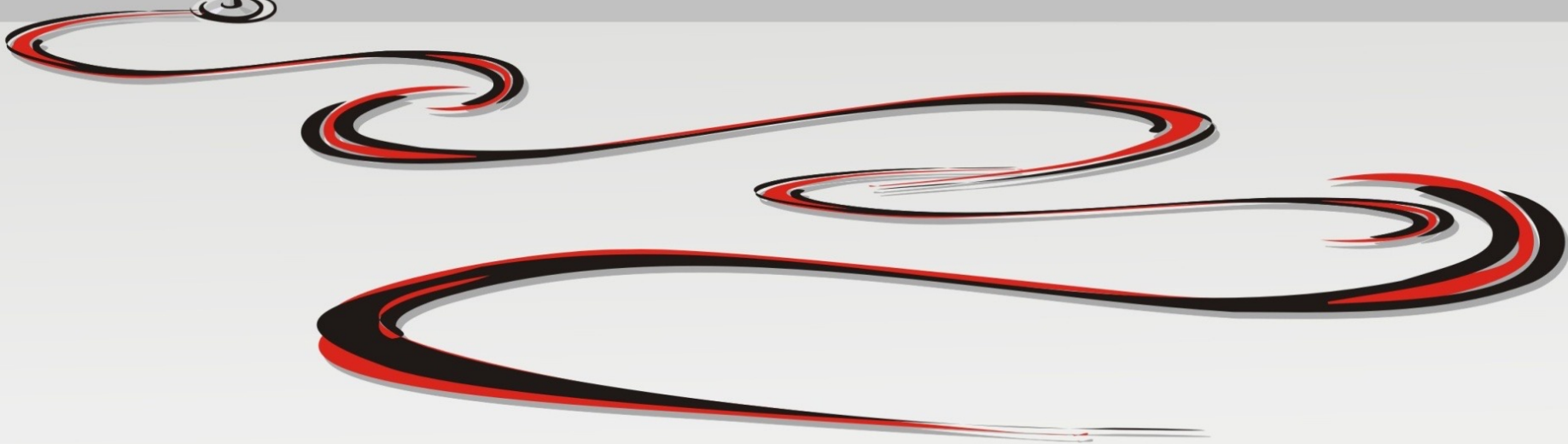


Mobile Blood Donation Logistics: Case for Turkish Red Crescent

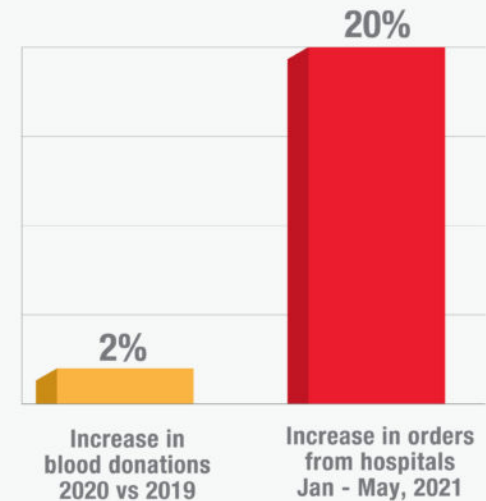
Şahinyazan, Feyza Güliz, Bahar Y. Kara, and Mehme
Rüştü Taner. "Selective vehicle routing for a mobile
blood donation system." *European Journal of
Operational Research* 245.1 (2015): 22-34.



Blood Donation

Demand for Blood Outpaces Supply

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



Blood Shortage Facts

- Requests for blood from hospitals is now **10 times higher** than the increase in donations, leading to a local health emergency that puts patients in need of blood at risk.
- The center saw a **2%** increase in blood donations last year, despite having more than **1,000 fewer** blood drives because of the pandemic.
- But orders for blood are up **20%** Jan - May, compared to the same time last year.
- An adequate blood supply requires **200 more** blood donors every day. That adds up to a need for about **600 donors** a day in total.



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
 - Voluntary Blood Donation: *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

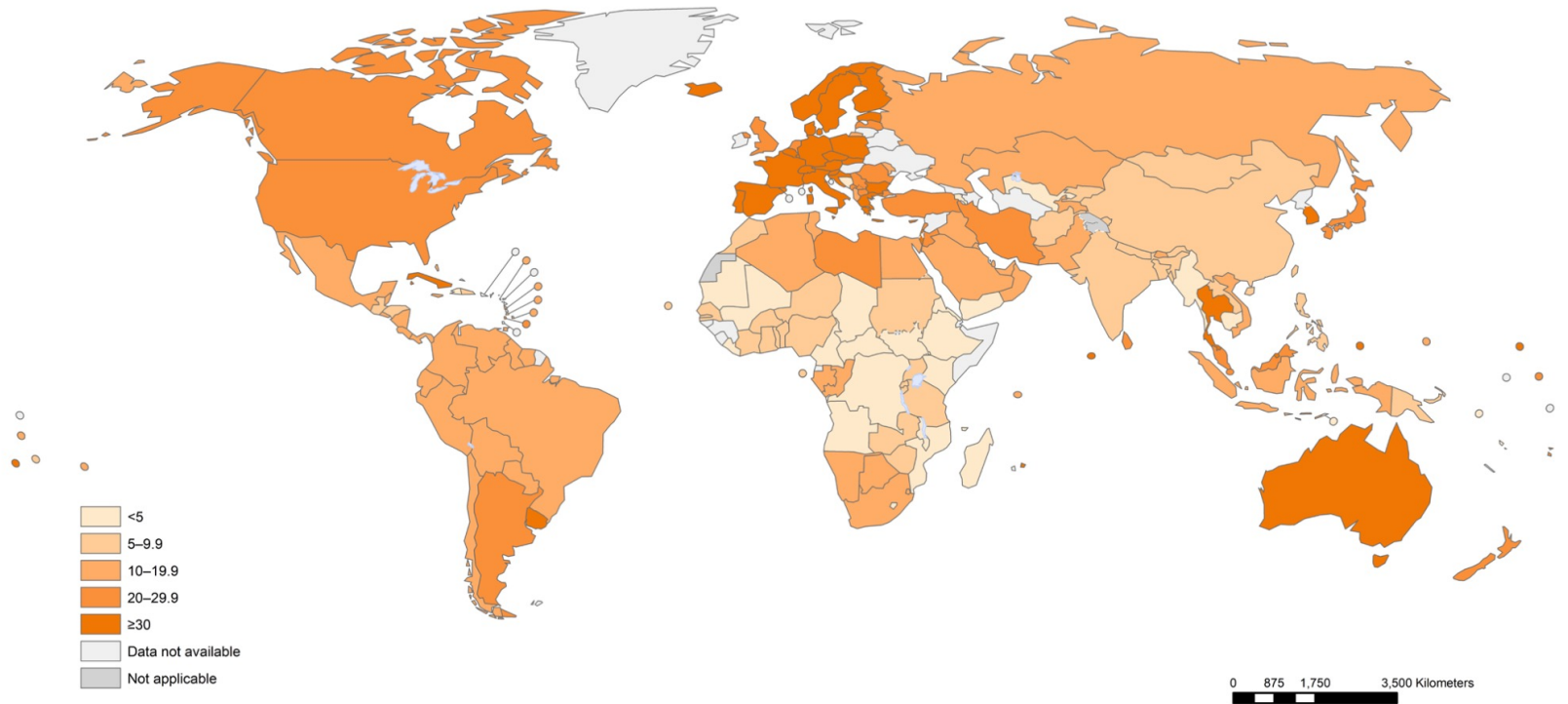


- Consequences of selling blood:
 - *Tests may not be accurate*
 - *Sellers lie about their physical conditions*
 - *Diseases may spread quickly*
 - *Receiver's medical condition get even worse*

Blood Logistics



Figure 5. Whole blood donations per 1000 population, 2018



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: World Health Organization
Map Production: Blood and other products of human origin
World Health Organization



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Figure 1. Blood donation amounts

Blood Logistics

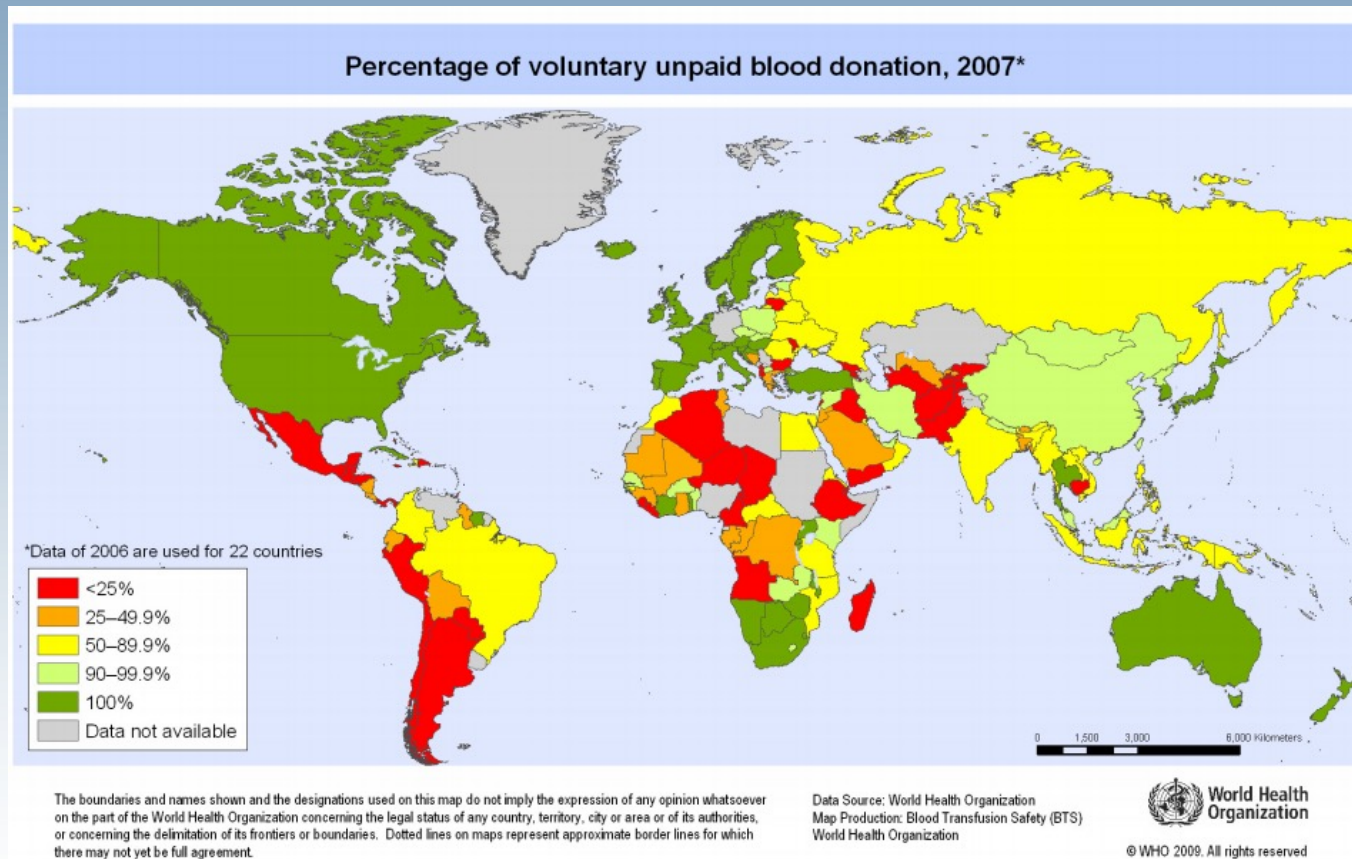


Figure 2. Percentage of voluntary blood donation

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

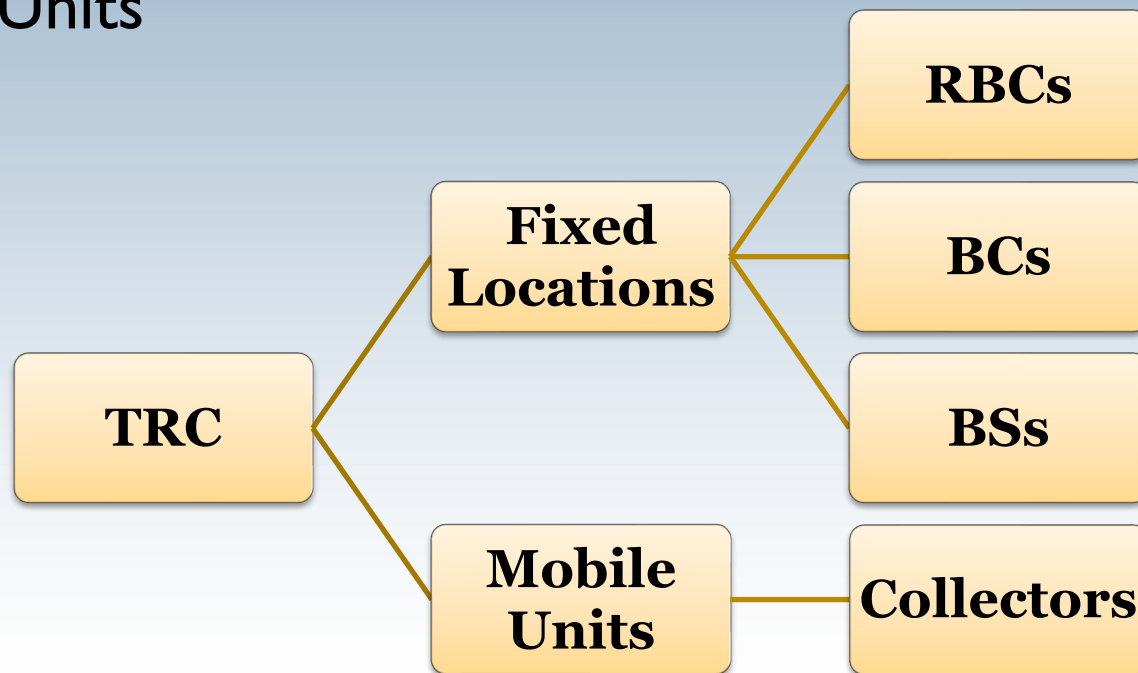


Figure 3. Components of TRC

Blood Logistics



- Fixed Points

- **Regional Blood Centers**

- *Centers with developed opportunities*

- **Blood Centers**

- *Centers with **less** developed opportunities, but more common*

- **Blood Stations**

- *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.

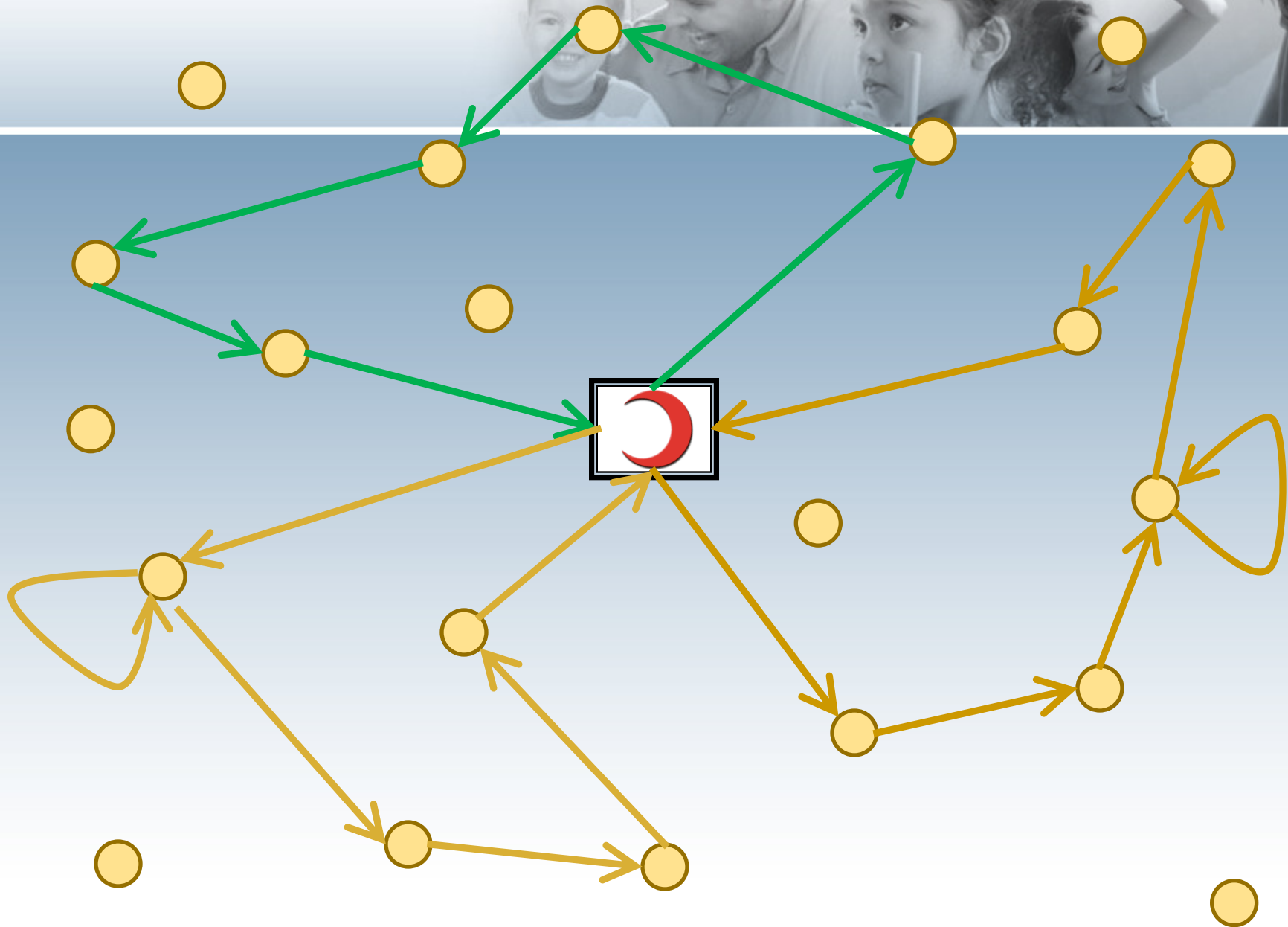


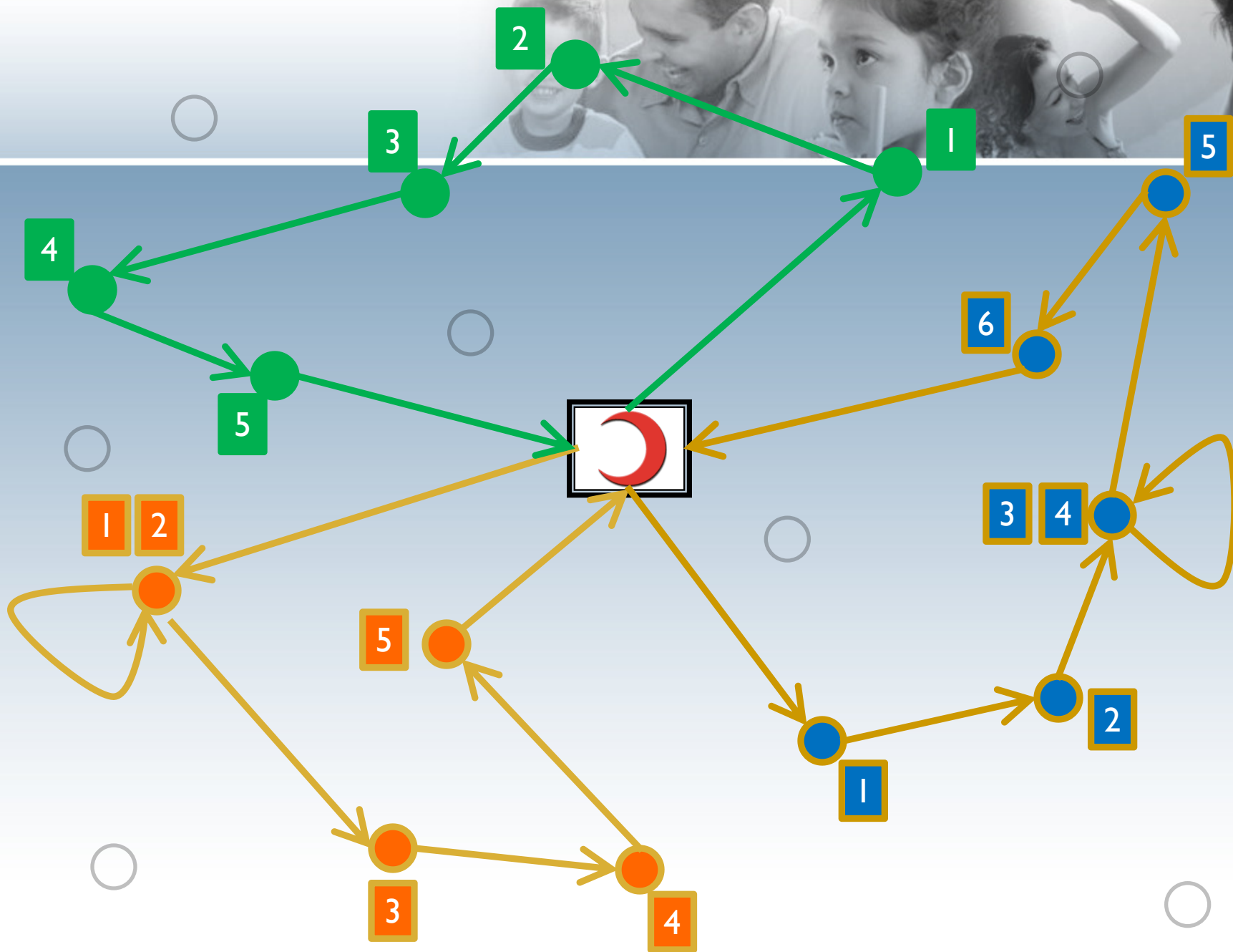
Problem Definition

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

5



6



3 4

1 2

5

2

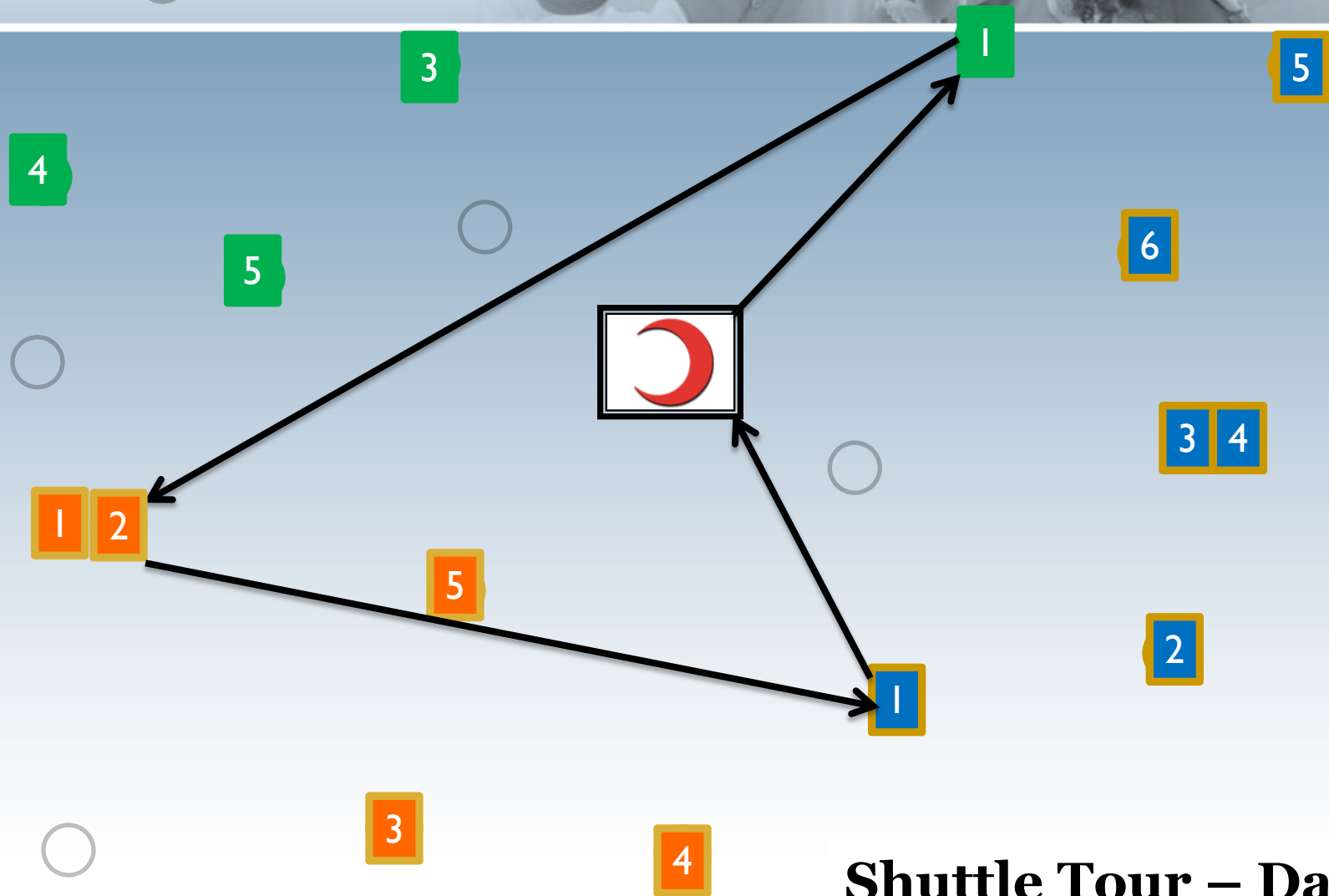
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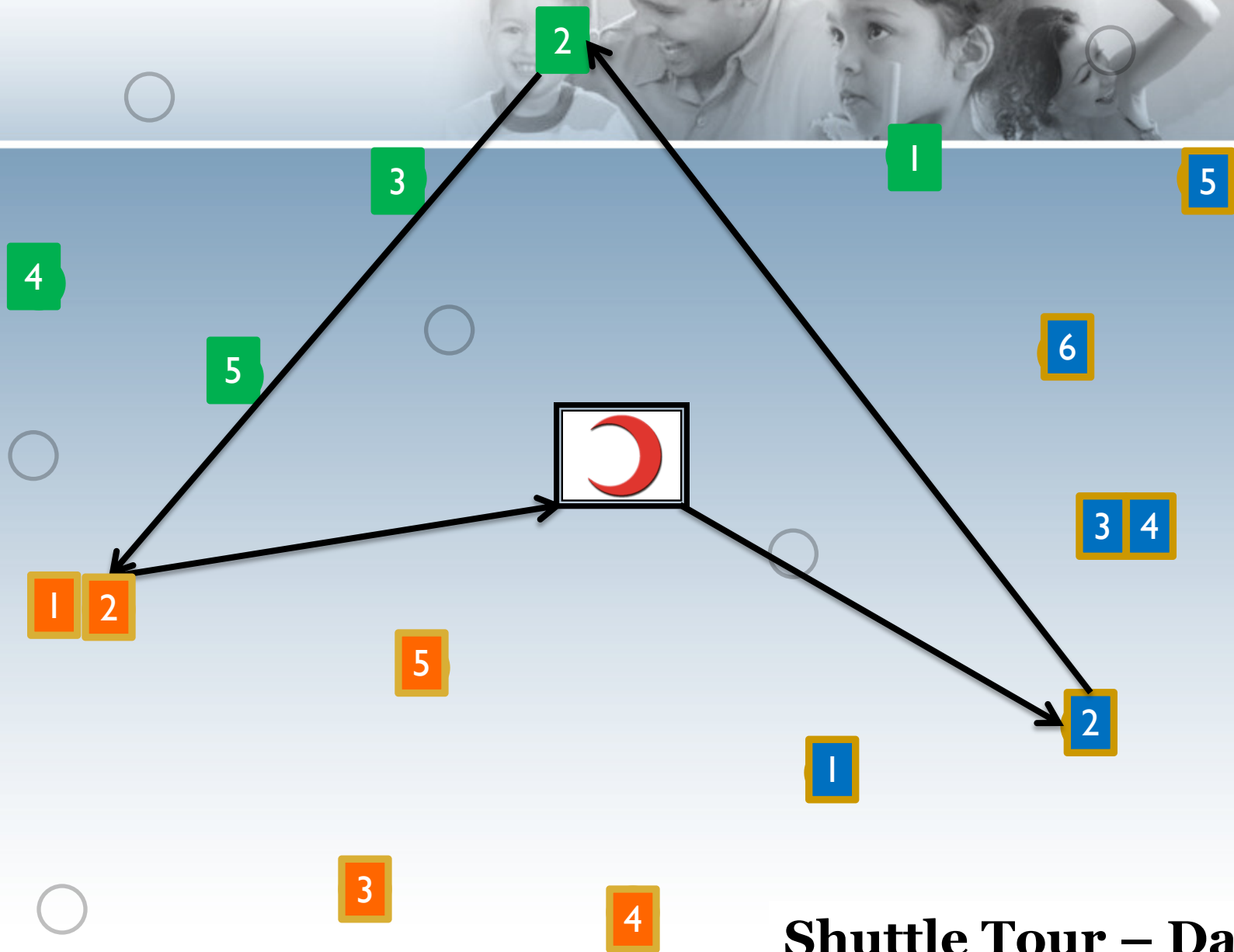
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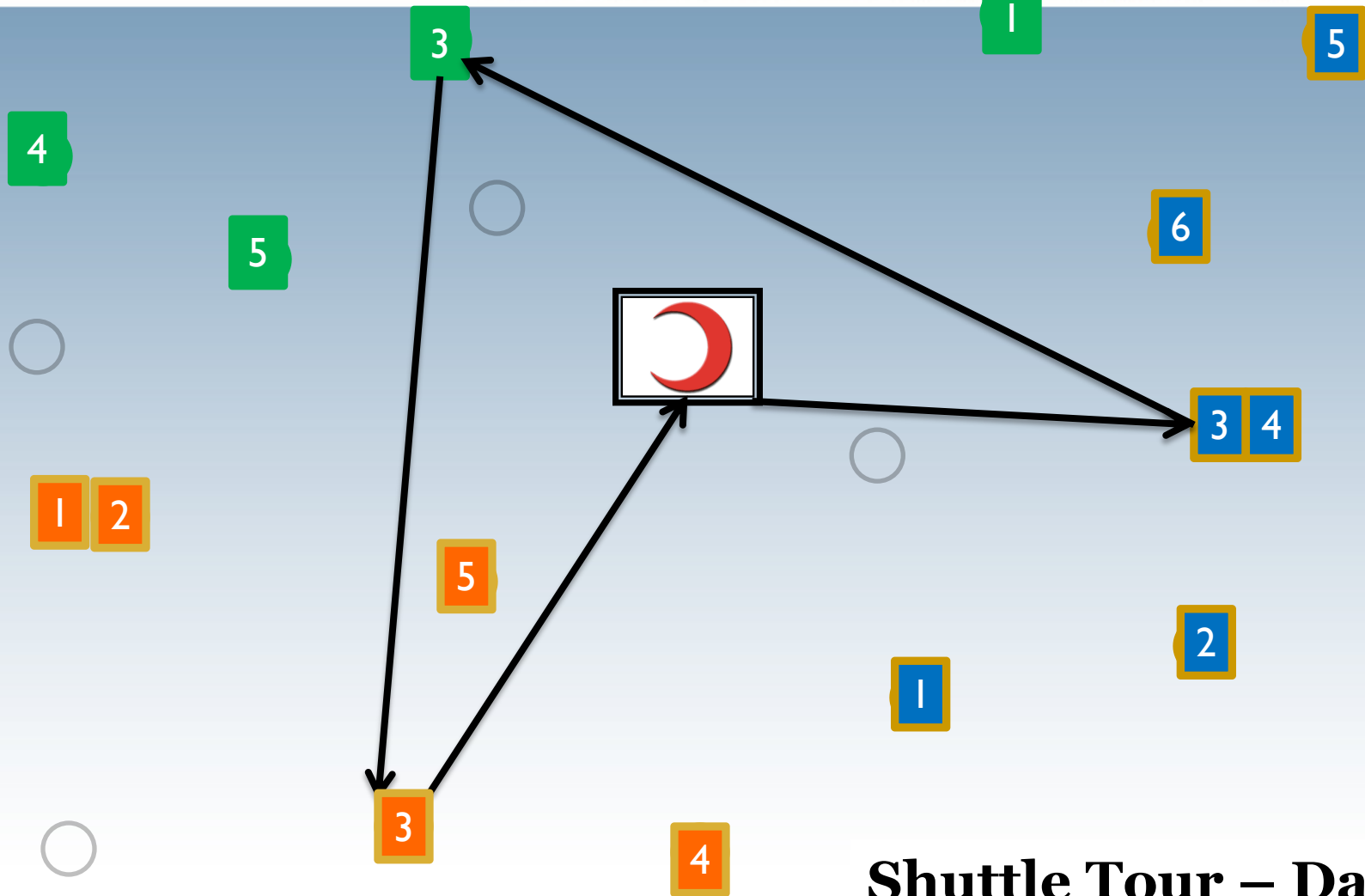




Shuttle Tour – Day 1



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)

New problem

→ *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



- $G = (N, A)$
- $N \setminus \{I\}$ is the set of potential stops of the bloodmobile
- $\{I\}$ 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
 - If a blood mobile visits v'' , it means the bloodmobile stays in v for 3
 - 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 2 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:

$$c'_{ij'} = c_{ij}, \quad \forall i \equiv i' \pmod{|N|}, \quad \forall j \equiv j' \pmod{|N|}$$

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:

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

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

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

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

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

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

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

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

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

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

Bloodmobile const.

Model Development

(MinCost-B*-Blood) – Shuttle const.

Shuttle constraints

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

$$\sum_{i \in N'} Y_{j1d} = Z_{jd}, \quad \forall j \in N', \forall d \in \{1, \dots, D-1\}$$

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

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

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

$$V_i \geq 0, \quad \forall j \in \{2, \dots, N'\},$$

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:

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

subject to

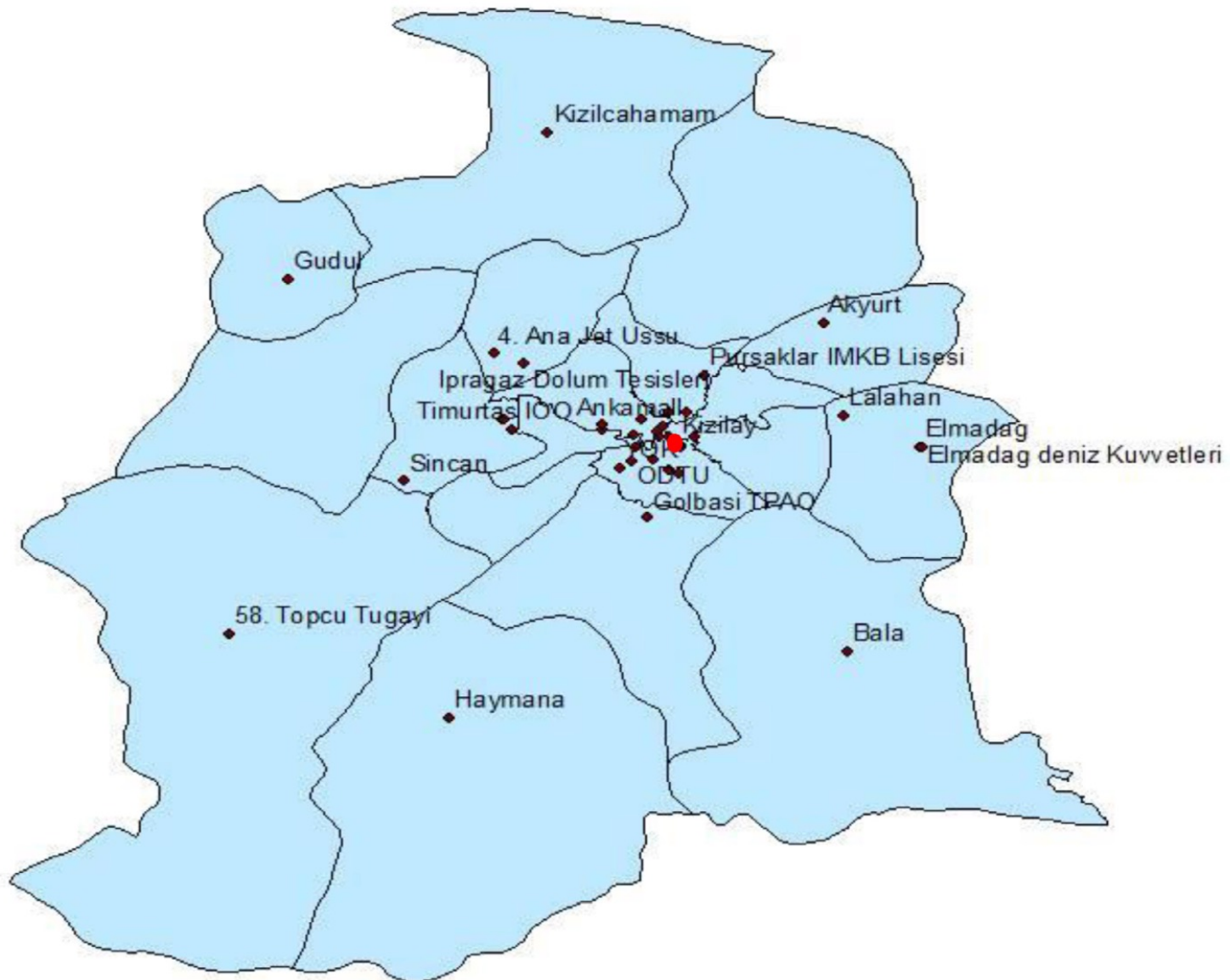
*Bloodmobile const's of
MinCost-B*-Blood*



Computational Results

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

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

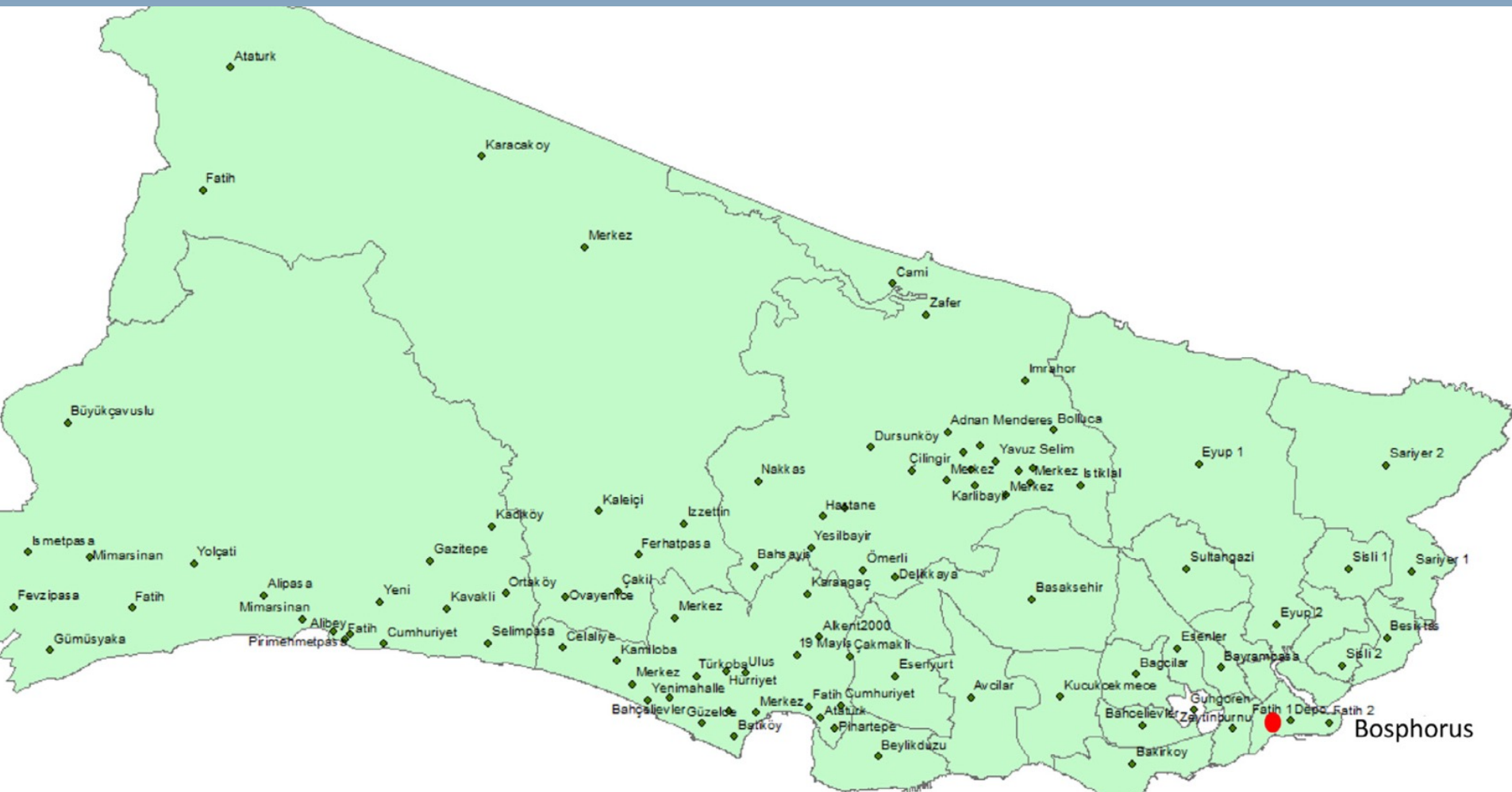


Computational Results

- Istanbul Case:
 - Hypothetical data based on GIS
 - population $\approx$ 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

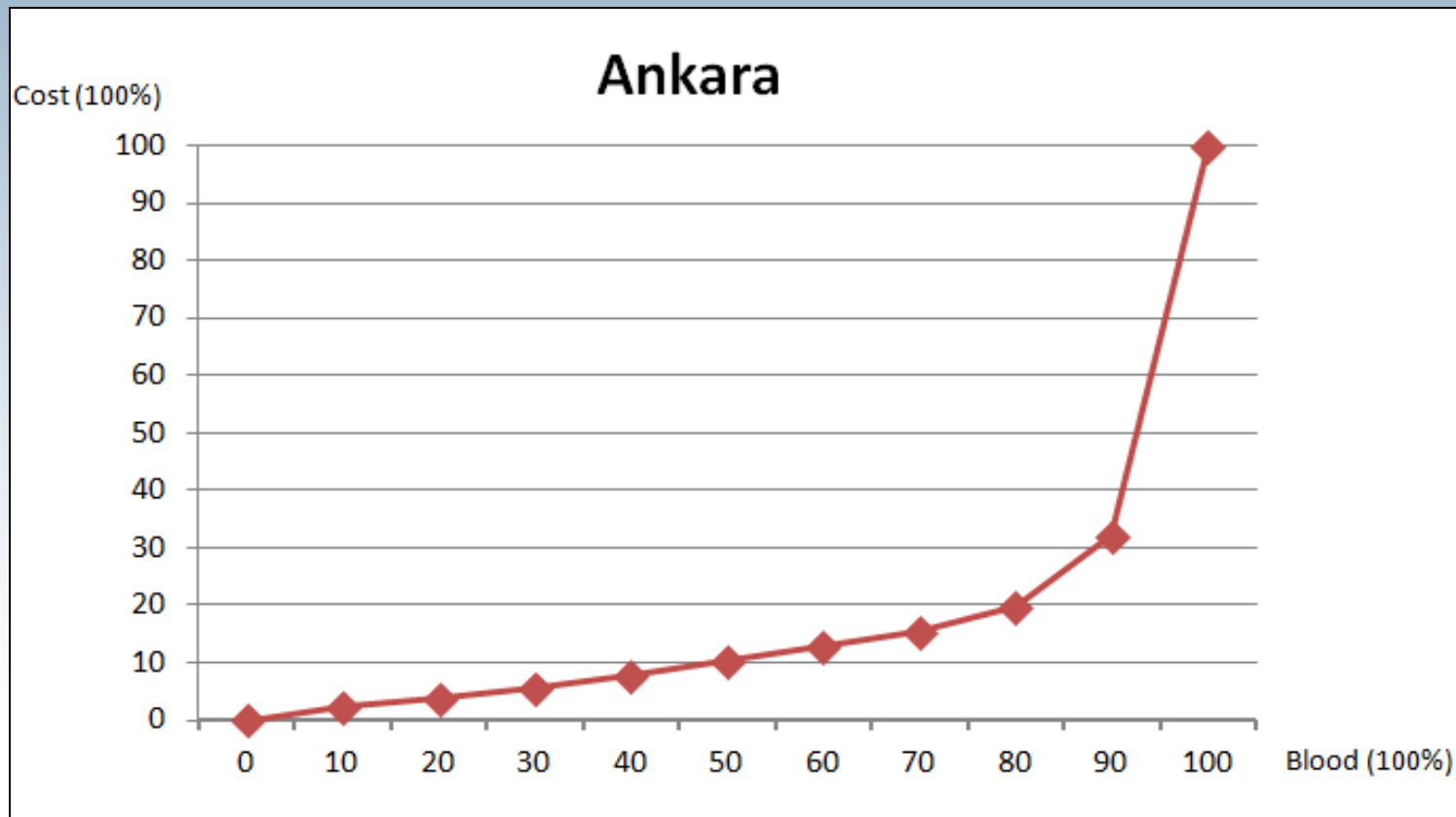


Computational Analysis

- 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*.

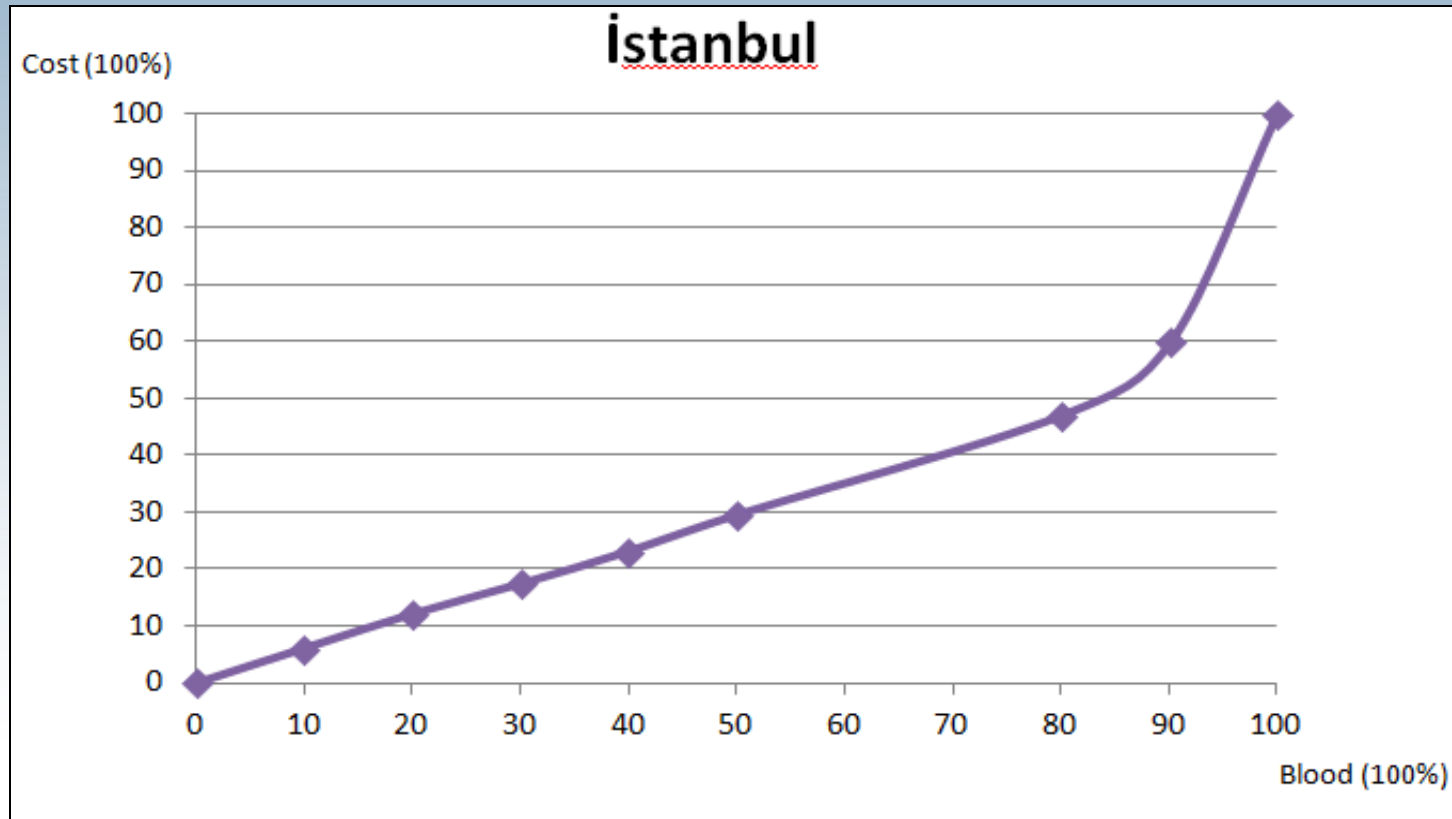
Computational Analysis

- Ankara case:



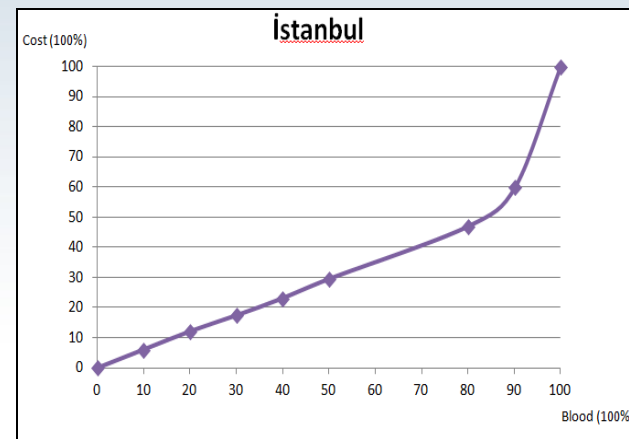
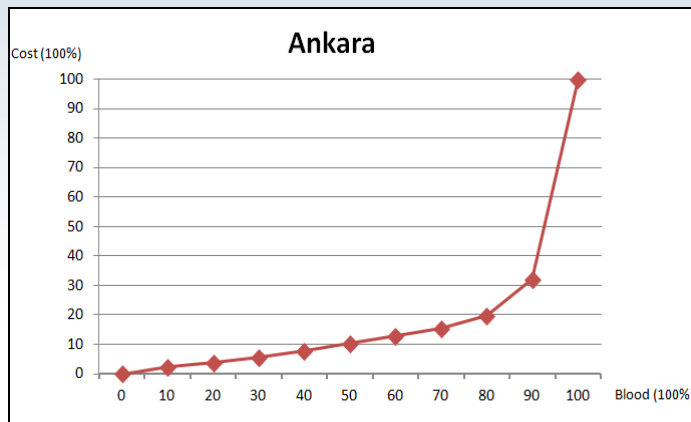
Computational Analysis

- 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?

