Design of Blood Supply Chain and Application to Marmara Region in Turkey

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***Abstract*—Blood transfusion is needed due to operations, diseases or accidents. Millions of people's health depends on the success of their blood transfusion. Planning and management is required to supply blood, test against diseases, produce blood products, store t hem and transport them to hospitals. A blood supply chain network design such as Blood Donation Centers (CBM), Regional Blood Centers (RBC), Destruction Centers (DM), and hospitals are addressed. To formulate the problem, the General Algebraic Modeling System (GAMS) software was applied to the Mixed Integer Model. When the number of RBC in Marmara region decreased from 3 to 2, opening and transportation costs increased to $5.37 million. When the number of RBCs increased from 3 to 4, opening and transportation costs decreased to $3.94 million.**

***Index Terms*—Blood Banking; Blood Transfusion; Optimization; Supply Chain Design**

I. Introduction

It is estimated that a total collection of 112.5 million blood donations were made in the 180 countries during the reporting period. Of these, 100.6 million were whole blood donations and 11.9 million were apheresis donations. These donations were collected from all types of blood donors: voluntary non-remunerated, family or replacement, and paid. This estimation has taken into consideration the partial data provided by countries [1].

The Blood Donation system (BD) aiming at providing an adequate supply of blood to Transfusion Centers (TCs) and hospitals. Blood is necessary for several treatments and surgeries, and still a limited resource. The need for blood is about ten million units per year in the USA, 2.1 in Italy and 2 in Turkey; moreover, people still die in some countries because of inadequate supply of blood products. Hence, BD plays a fundamental role in healthcare systems, aiming at guaranteeing an adequate blood availability to meet the demand and save lives [2].

The human heart is a pump created from muscle tissue. It has four compartments; in upper side the right atrium and the left atrium in lower side the right ventricle and left ventricle. A special group of cells called the sinus node is located in the right atrium. Each contraction represents a heartbeat. The heart is in a systolic phase when contracted and is in a diastolic phase when it stops. It takes about a minute for the blood to circulate through the cardiovascular system and pumping oxygenated blood into the body. The sinus node provides electrical stimuli to contract heart and pump blood. The power of the heart can be calculated by multiplying the flow by pressure. Turbulent blood flow through the vessels can be heard as a soft ticking while measuring blood pressure; this sounds are known as Korotkoff sounds. Although there are 5 recognized Korotkoff sounds only 2 are normally recorded. The first sound heard indicates systolic pressure and last sound is recorded as diastolic pressure. Cardiac output is the measurement of blood flow rate from the heart through the ventricles [3]. An average person's body is circulating 5 liters of blood per minute and the blood flow rate is 10^{-4} m^3/s. The pressure in the heart is approximately 10^4 Pa. It is accepted that systolic blood pressure of people is 80 mm Hg column and diastolic blood pressure is 120 mm Hg column. The 10 mm Hg column pressure is equal to 1.333 kPa. The cardiac output is $10^7 cm^3/s$. The mechanical power can be found as 1.71 W. Using efficiency value of 0.20 the chemical power is found as 8.55 W. Based on mechanical power it is seen that the human heart performs energy of 3.77 GJ during the 70 years of life span. This amount of energy is equivalent to approximately 100 liters of gasoline.

Thousands of people need a blood transfusion every day due to surgery, illness or accidents. The health of millions of people depends on the success of blood transfusion. Providing blood through donations, testing against diseases, producing and storing blood products, transporting them to the hospital and delivering them to the patient are the main activities of blood banking. These tasks need to be carefully planned, managed and controlled. To secure the supply blood a regulation published by the Ministry of Health in 2008. Turkish Red Crescent was authorized to collect blood and distribute blood products. The Turkish Red Crescent on blood services faces some problems due to insufficient blood donations and inefficient logistics system and planning decisions. Countries in the low-income and low-middle income group represent 2% and 22% of global donations respectively while they represent 9% and 39% of the global population. 46 countries in the African Region collected approximately 5.6 million blood donation units. Although these countries are hosting about 13% of the global population they are only 4% of global donations. 11 countries in the Southeast Asian Region reported collecting 15% of global blood donations but these countries represent 26% of the global population. In the European Region reported donations represent 30% of the global total but only 11% of the global population lives in the region. Blood donation system can be collected 12 hours before the

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emergence of blood donation by donating system in an electronic environment [4]. For the delivery of blood to the necessary places an application has been downloaded to the mobile phones and the choice is made for the demand and distribution between the regional blood centers and hospitals [5]. In spite of all the developments in the field of medicine and technology there is no substitute for blood, blood components and blood derived components. Blood is a treatment tool that is human and has no other alternative to obtain it. Today the countries that have established problems in the field of blood banking and have established an effective organization have defined blood banking activities in two stages. Donation Blood Banking is about safe, voluntary, regular conscious providing blood without waiting for a response performing laboratory procedures for donated blood, keeping blood and delivering to hospitals. Transfusion Blood Banking refers to the use of blood for patients and monitoring of the information recorded after use. Blood banking systems in developed countries working in line with their health policies can be summarized as follow:

The American Red Cross meets more than 40% of the blood needs of the country processes it and distributes it to 3000 hospitals and transfusion centers throughout the country. Each year the Red Cross receives 6.5 million units of blood donation from approximately 4 million blood donors and distributes more than 9 million blood components.

German Red Cross blood transfusion services receive 3.5 million whole blood donations per year. With the donations made. 80% of the country's blood needs are met and there are 2 million volunteer blood donors. Japanese Red Cross donation blood banking services are provided 7 regional blood centers. According to the blood banking system applied in the country, 3 different blood donation types are observed. The number of annual blood donations is 2 million units. High-income countries collect 47% of global donations, while their population is only 19% of the global population. Low-income and low-income middle-income countries account for 2% and 22% of global donations representing 9% and 39% of the population. In the African region 46 countries gathered approximately 5.6 million blood donations. Although these countries are hosting about 13% of the global population, they are only 4% of global donations. In the Southeast Asian Region 11 countries reported collecting 15% of global blood donations but these countries represent 26% of the global population. In the European Region, reported donations represent 30% of the global total but only 11% of the global population lives in the region. According to the reports of 180 countries 74 countries provide more than 90% of the blood through voluntary donations. Fifty seven countries provide more than 99% of the blood through voluntary donations. More than 50% of the 73 countries are provided with relatives donations. Twenty two countries reported that they still collect blood as a toll [1].

In 1957, the Turkish Red Crescent opened its first Blood Centers in Istanbul and Ankara and the country started to meet the needs of the blood through donations based on volunteerism. In the first year, the need coverage ratio which is 20%, has increased to 80%. The part that cannot be met by volunteer blood donation is mostly met by the hospital blood centers by the replacement of blood. The ratio of voluntary blood donation population in developed countries this rate is around 3.6% in Turkey amounted to 5%. The inability of the number of volunteer blood donors is an important problem for us. Turkish Red Crescent will provide enough blood to meet the needs of the whole country within the framework of a plan made by the end of 2020. Blood Component Identification and Traceability System used to determine the number of blood use in the country. In 2016, the country's need for blood was seen as 2.7 million units. In 2016, the Turkish Red Crescent met with 2141765 units of blood donation, which provided 79% of the country's blood need. In 2016, 86% of male and 14% female donors were donated by blood donors. In 2016, 2141765 units of blood donation were obtained. The demands of the cities in the Marmara region (cities; Istanbul, Edirne, Kirklareli, Tekirdag, Canakkale, Kocaeli, Yalova, Sakarya, Bilecik, Bursa, and Balikesir) are met by European RBC, Northern Marmara and Southern Marmara Region Blood Centers [6].

There are three elements of blood banking studies by the Turkish Red Crescent: Regional Blood Centers, Blood Donation Centers, and Transfusion Centers. The Regional Blood Center (RBC) is the most comprehensive unit of blood banking which is established in the regions to be determined by the Ministry working in cooperation with blood donation and transfusion centers in its own region and capable of meeting the blood. The blood donation center (BDC) is a unit that takes blood from the donor and works in connection with the RBC. It is the unit which is opened by RBC in voluntary unrequited and regular donor organizations organized by RBC in the places deemed necessary for safe blood supply. Transfusion Center (TC) is the unit that does not have the power to take blood from the blood donor except for emergency cases is the unit that provides the blood or its component for the purpose of cross-comparison for transfusion and other tests required for use by patients. Volunteer citizens who want to give blood donations give blood in blood donation centers and these bloods are regularly brought to the Blood Zone. Blood All bloods brought here from donation centers are tested to produce erythrocyte plasma and platelets after testing. Blood samples from blood centers are tested and blood products are produced from the appropriate ones and blood is delivered to the transfusion centers where the need is given to patients [7].

II. Blood Components and Features

Due to the fact that whole blood use is prohibited by the Ministry of Health except for emergencies. The collected bloods are divided into three components; platelets, plasma and erythrocytes. Blood is the only fluid tissue in the body. It appears to be a viscous homogeneous liquid but the microscope reveals that blood has both cellular and liquid components. Blood is a specialized type of connective tissue in which living blood cells called the formed elements are suspended in a nonliving fluid matrix called plasma. The collagen and elastic fibers typical of other connective tissues are absent from blood but dissolved fibrous proteins become visible as fibrin strands during blood clotting. Plasma is the main component of blood and is mostly composed of water.

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Proteins ions nutrients and wastes are also available. The plasma the liquid component of the blood can be isolated by turning a blood tube at high speed in a centrifuge. The dense cells and platelets pass through the base of the tube to form red and white layers while the plasma remains at the top and forms a yellow layer.

Plasma is about 90% water and the remaining 10% consists of ion. Protein, nutrients, waste, and dissolved gases. The ions, proteins and molecules contained in the plasma are important for maintaining the pH and the osmotic equilibrium. The main protein in human plasma is albumin. Approximately 30% of the total product demand belongs to the plasma. Plasma can be stored at -25°C for up to 36 months. The plasma consists of approximately 55% of the blood.

Erythrocytes specialized cells that circulate in the body and give oxygen to tissues. In humans red blood cells are small and biconvex (the finest in the center only 7 - 8 μm in size) and do not contain mitochondria or nuclei when they mature. These properties allow red blood cells to effectively perform the oxygen transport task. The small-size and double-sided shape creates an additional area for hemoglobin. a key protein used in oxygen transport while increasing the volume ratio of the surface area that improves gas exchange. Lack of mitochondria prevents red blood cells from using any of the oxygen they carry. Thus the amount of O_2 transmitted to the tissues of the body is maximized.

Red blood cells take oxygen in the lungs and release this oxygen into the surrounding tissues as they circulate the body. Red blood cells also play an important role in transporting a waste product carbon dioxide from the tissues to the lungs. Some of the carbon dioxide binds directly to hemoglobin and red blood cells also carry an enzyme that converts carbon dioxide to bicarbonate. The bicarbonate is dissolved in plasma and transported to the lungs where it is converted to carbon dioxide and released. The average life of red blood cells is 120 days. Old or damaged red blood cells are broken down in the liver and spleen and new ones are produced in the bone marrow. Red blood cell production is controlled by the erythropoietin hormone released by the kidneys in response to low oxygen levels. This negative feedback loop allows the number of red blood cells in the body to remain relatively constant over time. Red blood cells comprise about 45 percent of the blood.

Platelets also called platelets are parts of the blood involved in blood clotting. They are produced by breaking up large cells called megakaryocytes. Each one is shredded while receiving 2000-3000 platelets. The platelets are roughly disc-shaped and have diameters less than 2-4 μm. When a lining of a blood vessel is damaged platelets form a sticky plug and are pulled into the wound area. Platelets not only attract other platelets but also make them sticky. It is the conversion of fibrinogen. a water-soluble protein found in blood plasma into fibrinogen-insoluble filamentous fibrin. Fibrin forms the threads that strengthen the platelet plug and creates a clot that prevents further blood loss. The platelet can be stored at 20-24ºC for up to five days with continuous shaking. White blood cells also called leukocytes are less common than red blood cells and constitute less than 1% of blood cells. Their role is also very different from red blood cells: they primarily participate in immune responses to recognize and neutralize invaders such as bacteria and viruses. White blood cells are larger than red blood cells and. unlike the red blood cells they have a normal core and mitochondria. White blood cells are found in five main types; neutrophils, eosinophils, basophils, monocytes, and lymphocytes [8].

III. Transports and Storage of Blood and Blood Components

There are eight blood components as ES, CRYO, APTT-P, P-ES, TK, APTT, TDP, and HPLT used by Turkish Red Crescent in 2017 [6]. Fresh frozen plasma, cryoprecipitate reduced plasma, and cryoprecipitate can be stored at temperatures between 18ºC and -25ºC for up to 3 months and it can be stored up to 36 months at temperature below -25°C (Fig. 1). These conditions should be kept as close as possible during transport. If the storage temperature does not change during defrost, no-frost freezers can be used. The temperature in the freezer should be recorded continuously.

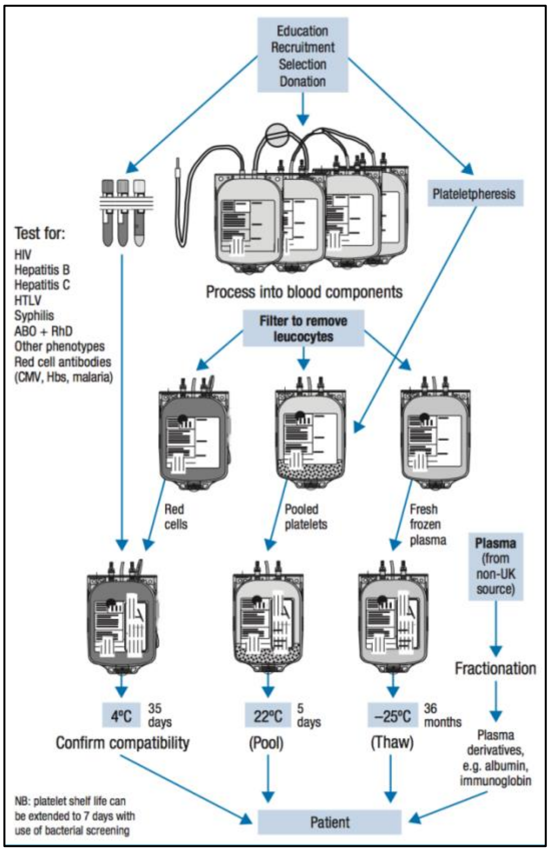

Fig. 1. Blood components and production of blood derivatives

The alarm system must be both visually and audibly alerted and checked regularly. Separate areas should be identified for different types of components and each area should be clearly marked to prevent errors. All data regarding the preparation, storage and transport of plasma components should be recorded. All process and technology (software and equipment) should be documented. It is kept as close as possible to the recommended storage temperature during transport and stored under the recommended conditions if it will not be used immediately at the point of treatment [9, 10].

If transfusion necessary in any patient should be ensured about right blood, right patient, right time, and right place. Following principles underpin safe and effective transfusion

practice [9]:
1 Transfusion should only be used when the benefits outweigh the risks and there are no appropriate alternatives.
2 Results of laboratory tests are not the sole deciding factor for transfusion.
3 Transfusion decisions should be based on clinical assessment underpinned by evidence-based clinical guidelines.
4 Not all anemic patients need transfusion; there is no universal 'transfusion trigger'.
5 Discuss the risks, benefits and alternatives to transfusion with the patient and gain their consent.
6 The reason for transfusion should be documented in the patient's clinical record.
7 Timely provision of blood component support in major haemorrhage can improve outcome – good communication and team work are essential.
8 Failure to check patient identity can be fatal. Patients must wear an ID band with name, date of birth, and unique ID number. Confirm identity at every stage of the transfusion process. Patient identifiers on the ID band and blood pack must be identical. Any discrepancy transfusion not been applied.
9 The patient must be monitored during the transfusion.
10 Education and training underpin safe transfusion practice.

ABO-incompatible red cell transfusion is often fatal and its prevention is the most important step in clinical transfusion practice.

Alloantibodies produced by exposure to blood of a different group by transfusion or pregnancy can cause transfusion reactions, haemolytic disease of the fetus and newborn (HDFN) or problems in selecting blood for regularly transfused patients.

To prevent sensitisation and the risk of HDFN, RhD negative or Kell (K) negative girls and women of child-bearing potential should not be transfused with RhD or K positive erythrocytes except in an emergency.

Use of automated analysers, linked to laboratory information systems, for blood grouping and antibody screening reduces human error and is essential for the issuing of blood by electronic selection or remote issue.

When electronic issue is not appropriate and in procedures with a high probability of requiring transfusion a maximum surgical blood ordering schedule (MSBOS) should be agreed between the surgical team and transfusion laboratory.

There are more than 300 human blood groups but only a minority cause clinically significant transfusion reactions. The two most important in clinical practice are the ABO and Rh systems [9]. The use of automated analyzers associated with laboratory information systems blood grouping, antibody screening and blood selection by electronic selection or remote notification reduce human errors. It is to be agreed between the surgical team and the transfusion laboratory that the maximum number of surgical blood sets is required for transfusion and where the electronic issue is not suitable and the methods are highly probable.

There are more than three hundred human blood groups, but only a small proportion of them cause clinically significant transfusion reactions. The two most important factors in clinical practice are ABO and Rh systems.

Blood group antigens are molecules on the surface of red blood cells. Some like ABO groups are also found in platelets and other tissues of the body. For most blood groups, genes have been identified, and tests based on this technology are increasingly undergoing clinical practice.

Blood group antibodies are usually produced when a person is exposed to blood by a different group through transfusion or pregnancy. This is a particular problem in patients requiring repeated transfusion for conditions such as thalassemia or sickle cell disease, and may cause difficulties in providing fully compatible blood if the patient is vaccinated. Some antibodies react with red cells that have a normal body temperature of around 37 ° C (warm antibodies). Others are active only at low temperatures (cold antibodies) and do not usually cause clinical problems despite laboratory tests.

ABO blood group system is the first system discovered since anti-A, and anti-B mainly cause visible agglutination of erythrocytes in group A or B in the IgM immunoglobulin class and in laboratory mixing tests. Many other blood group antibodies, such as those against Rh antigens have a smaller IgG molecule and do not directly cause agglutination of erythrocytes. The Direct Antiglobulin Assay (DAT) is used to detect antibodies found in circulating erythrocytes after autoimmune hemolytic anemia or blood transfusion incompatibility. Blood plasma antibodies in plasma are shown by indirect antiglobulin test (The Indirect Antiglobulin Test. IAT).

Nearly all clinically important red cell antibodies can be detected by an indirect antiglobulin assay (IAT) antibody screening performed at 37°C.

There are four main blood types: A, B, AB, and O. All normal individuals have antibodies to A or B antigens that are not present in their erythrocytes (Table I). The frequency of ABO groups differs in different ethnic populations and should be taken into consideration when receiving these representative blood donor panels. For example people of Asian descent have a higher B group than white Europeans. Those blood group individuals are sometimes known as universal donors because they do not have A or B antigens in their erythrocytes. However plasmids contain anti-A and anti-B if present in high titration and some has the potential to hemolysis erythrocytes of non-O receptors.

TABLE I: THE ARRANGEMENT OF CHANNELS DISTRIBUTION OF ABO BLOOD GROUPS AND ANTIBODIES

Blood Group	Antigens on erythrocytes	Antibodies in plasma	UK blood donors
O	None	Anti-A and anti-B	47%
A	A	Anti-B	42%
B	B	Anti-A	8%
AB	A and B	none	3%

The second system is called the Rhesus System and is classified as Rhesus Positive (+) and Rhesus Negative (-). The two systems combine O-, O+, A-, A+, B-, B+, AB- and AB+ to define eight different blood groups.

Table II shows the compatibility of the blood group. A person with an AB + blood group can take blood from all the important blood groups. People with an o-blood group can only take blood from donors with the same blood group [9, 12].

TABLE II: BLOOD GROUP COMPATIBILITY

Blood group	Donor	Recipients
O-	All	Only O-
O+	AB+. A+. B+. O+	O- and O+
A-	AB-. AB+. A+. A-	O- and A-
A+	AB+. A+	O-. O+. A-. A+
B-	B-. B+. AB-. AB+	O-. B-
B+	B+. AB+	O-. O+. B-. B+
AB-	AB-. AB+	O-. A-. B-. AB-
AB+	Only AB+	All

The most common blood group is Rh positive in Turkey, the most rare blood group AB Rh negative. The 37% of Turkish people have A-positive blood group and 1% of the AB-negative blood group. According to the Turkish Red Crescent data, blood group distribution of blood donors in 2016 is given in Table III [6]. In the world the most common blood group is O-positive, accounting for about 46% of the world's population.

TABLE III: BLOOD GROUP COMPATIBILITY FREQUENCY OF BLOOD GROUP DISTRIBUTION IN TURKEY

Blood group	A+	O+	B+	AB+	A-	O-	B-	AB-
Percentage		30	14	7	5	4	2	1

Giving blood enables many people to maintain their normal healthy lives. Thousands of patients have thousands of blood transfusions each year in Irish hospitals. Only 3% of the Irish population gives blood and provides blood to more than 4 million people. 3000 blood donors are needed every week in Ireland. One in four needs blood transfusions at some point in their lives. The most common blood type in Ireland is O positive and the rarest blood group is AB negative. The blood group distribution of Irish blood donors is given in Table IV [12].

TABLE IV: FREQUENCY OF BLOOD GROUP DISTRIBUTION IN IRELAND

Blood group	O+	A+	B+	O-	A-	B-	AB+	AB-
Percentage	47	26	9	8	5	2	2	1

Blood group A+ has the highest frequency in Turkey and O+ has the highest frequency in Ireland.

IV. BLOOD SUPPLY CHAIN NETWORK DESIGN

In today's world supply chains are more complex than ever. Consumers' demand for new products and the still critical economic situation require companies and organizations to be more innovative and more cost-effective in their procurement and production as well as in their delivery. Nevertheless despite numerous successes the supply chain management discipline still cannot adequately address many practical real-world challenges [13].

Some researchers recommend the following in blood transfusion: Observations such as pulse, blood pressure, temperature, and respiratory rate should be undertaken and documented for every unit transfused. Minimum monitoring of the patient should include the following: Pre-transfusion observations taken and recorded no more than 60 min before the starting of the component transfusion. Observations 15 min after the starting of each unit and post-transfusion observations taken and recorded not more than 60 min after the end of the component transfusion [17].

There are 17 fixed blood donation centers (BDC) and 40 mobile donation points in 11 provinces in the Marmara region. There are three regional blood centers (RBC) in Kartal, Istanbul on the Asian side of Istanbul and in Bagcilar, and Bursa on the European side of Istanbul. In this region, there are 137 public hospitals and polyclinics as demand points. It is the essence of the problem that hospitals are late in responding to demand or that patients are victims because of excessive cost when demand is met or demand cannot be met. The problems caused by the lack of this system are +described in Figure 2 [18].

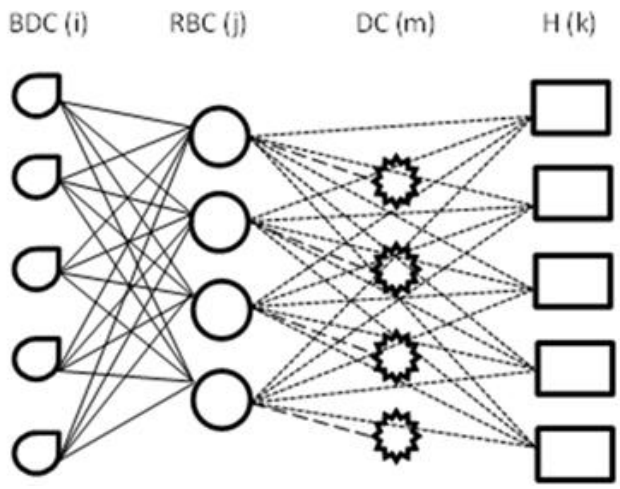

Fig. 2. Design of network diagram (see Symbols and Abbreviations List)

The cost of transport between RBC opening, destruction center, BDC and RBC is taken into consideration and the cost between RBC and destruction center is taken into consideration and the objective function that minimizes costs can be established as follows:

$$Min \sum_j f_j X_j + \sum_m a_m z_m + q \sum_i \sum_j b_{ij} v_{ij} + q \sum_k \sum_j d_{jk} h_{jk} + q \sum_j \sum_m r_{jm} g_{jm} \quad (1)$$

The constraints used in optimization are given in Table V.

TABLE V: CONSTRAINTS AND DESCRIPTIONS

No	Constraints	Description
1	$\sum_j v_{ij} = T_i$	The amount of product from BDCs. should be equal to the sum of collected blood products.
2	$\sum_j v_{ij} * \alpha = \sum_j h_{jk}$	The amount of blood removed from the BDC should be equal to the amount of blood that is sent to hospitals by 95 percent.

3	$\sum_j v_{ij} * (1-\alpha) \leq \sum_m g_{jm}$	The amount of blood removed from BDC to IM should be less than 5 percent.
4	$\sum_j h_{kj} \leq Kap_j * x_j$	The amount of blood removed from the RBC should not exceed the capacity of the RBC.
5	$\sum_j g_{jm} \leq W_m * z_m$	The amount of blood arrived the IM should not exceed the capacity of the IM.
6	$\sum_j h_{jk} \geq talep_k$	The amount of blood received from the BDC should be equal to or greater than the demands of the hospital.
7	$\sum_j x_j = 4$	Four of the potential RBCs should be opened.
8	$\sum_m z_m = 4$	Four of the potential IMs should be opened.

Hospital bed capacities, blood requirement per bed per week and the distances (km) between hospitals and the regional blood centers (RBC) are given in Table VI.

TABLE VI: HOSPITAL BED CAPACITIES, BLOOD REQUIREMENT PER BED PER WEEK AND THE DISTANCES (KM) BETWEEN HOSPITALS AND THE REGIONAL BLOOD CENTERS (RBC).
HOSPITAL=H, TRAINING=T, APPLICATION=A, UNIVERSITY=UNIV.
ISTANBUL NORTHERN MARMARA REGIONAL BLOOD CENTER=RBC1, BURSA SOUTHERN MARMARA REGIONAL BLOOD CENTER=RBC2, ISTANBUL EUROPEAN REGIONAL BLOOD CENTER=RBC3, AND BALIKESIR REGIONAL BLOOD CENTER=RBC4.

No	Hospital Name	Num of beds	Unit of blood	RBC1	RBC2	RBC3	RBC4
1	Akyazi Public H	100	1000	122.48	135.16	167.1	257.69
2	Alemdag	25	250	14.3	86.42	47.58	194.64
3	Arnavutkoy	201	2010	46.32	105.09	17.69	188.73
4	Ayvacik Public	35	350	276.52	239.31	248.7	126.38
5	Ayvalik Public H	102	1020	274.73	230	251.6	106.78
6	Babaeski Public	100	1000	186.23	214.23	142.1	216.26
7	Bagcilar T&R H	438	4380	28.61	86.63	17.08	177.87
8	Bakirkoy Dr.	150	1500	27.5	82.79	17.06	175.47
9	Balikesir	100	1000	179.32	124.13	168	3.93
10	Balikesir Ataturk	900	18000	181.45	125.15	170.3	0
11	Balikesir Public	400	4000	177.64	122.31	166.7	4.71
12	Balikesir Chest	100	1000	180.43	124.76	169.6	2.17
13	Balikesir	200	2000	179.3	123.87	168.1	3.32
14	Balya District H	30	300	187.57	140.41	169.8	30.71
15	Bandirma Public	300	3000	122.83	98	98.7	81.27
16	Basaksehir	100	1000	38.17	97.34	15.42	185.72
17	Bayrampasa	300	3000	26.91	87.38	19.72	180.04
18	Besiktas Sait	50	500	20.71	87.43	28.68	186.36
19	Beyoglu Eye	102	1020	20.9	84.67	25.64	181.44
20	Biga Public H	125	1250	178.1	154.38	147.1	88.72
21	Bigadic Public H	75	750	190.71	127.11	186.8	31.11
22	Bilecik Public H	100	1000	110.68	77.68	149.6	187.31
23	Bozuyuk Public	150	1500	135.4	93.15	172.1	189.36
24	Burhaniye Public	75	750	244.1	199.25	221.6	79.26
25	Bursa Public H	150	1500	81.7	9.4	99.5	117.76
26	Bursa Dortcelik	350	3500	80.49	14.95	92.56	111.23
27	Bursa Muammer	128	1280	54.62	18.5	78.88	140.83
28	Bursa Mudanya	100	1000	69.17	14.47	81.25	118.67
29	Bursa Sevket	1301	39030	81.44	10.2	101.8	123.32
30	Buyuk Orhan	10	100	129.41	57.47	141.6	86.95
31	Buyukcekmece	50	500	47.84	91.63	7.31	167.69
32	Camlica Military	50	500	14.44	82.25	32.52	183.75
33	Can Public H	100	1000	204.5	174.45	175.7	84.26
34	Canakkale 18	235	2350	252.53	229.56	218	138.78
35	Canakkale Public	100	1000	249.02	227.61	214.4	140.05
36	Catalca Ilyas	75	750	64.36	109.59	20.69	176.46
37	Cekirge Public H	525	10500	80.41	9.25	97.21	116.31
38	Cerkezkoy	200	2000	105.88	145	62.06	185.71
39	Corlu Military H	600	12000	117.87	146.12	73.58	172.28
40	Corlu Public H	400	4000	114.94	142.99	70.37	170.34
41	Darica Farabi	350	3500	25.21	62.23	68.58	181.94
42	Dr. Lutfi Kirdar	706	14120	0.288	72.48	44.23	181.12
43	Dr. Siyami Ersek	525	10500	16.08	82	29.96	182.77
44	Dursunbey	75	750	154.23	84.41	159.8	63.45
45	Edirne Public H	49	4090	230.02	258.63	185.5	252.31
46	Edremit Public H	200	2000	234.46	190.27	212.1	72.82
47	Enez Public H	10	100	260.92	259.61	218.1	198.63
48	Erenkoy Physical	101	1010	10.15	78.6	35.51	182.43
49	Erenkoy Spirit	250	2500	9.91	78.63	35.78	182.17
50	Esenyurt Public	200	2000	44.4	91.61	13.9	172.26
51	Eyup Public H	100	1000	25.28	88.59	23.12	183.55
52	Ezine Public H	100	1000	270.93	238.7	241	133.33
53	Gaziosmanpasa	300	3000	30.05	92.35	20.28	185.58
54	Gebze Fatih	400	4000	24.71	64.74	68.48	184.61
55	Geyve Public H	40	400	103.96	106.71	148.9	228.89
56	Golcuk Public H	171	1710	60.59	80.39	104.8	205.17
57	Gonen Public H	90	900	155.76	120.86	132.8	57.49
58	Goztepe T&R H	660	13200	12.66	79.72	33.08	182.32
59	Gumussuyu	300	3000	20.63	85.88	26.97	184.09
60	Haseki T&R H	206	2060	22.11	83.32	23.28	179.78
61	Haydarpasa	709	14180	16.03	82.02	30.52	181.55
62	Hayrabolu Public	50	500	177.2	197.47	132.5	189.51
63	Hendek Public H	100	1000	130.98	149.28	175.3	272.86
64	Inegol Public H	332	3320	96.62	40.85	126.9	146.88
65	Ipsala Public H	50	500	234.6	239	192.3	194.17
66	Istanbul T&R H	560	11200	22.24	82.67	22.8	178.42
67	Istanbul Physical	263	2630	29.63	84.5	15.12	175.4
68	Istanbul Kanuni	648	12960	38.25	91.65	8.17	177.08
69	Istanbul	52	520	4.82	75.88	40.52	182.69
70	Istanbul Univ	1042	31260	22.16	82.74	23.01	179.19
71	Istanbul	840	16800	23.33	84.17	22.22	180.8
72	Istinye Public H	100	1000	24.31	94.23	33.83	194.05
73	Ivrindi Public H	36	360	205.44	155.12	188.6	33.88
74	Izmit Women's	520	10400	69.85	95.55	114.3	221.28
75	Izmit SEKA	75	750	63.2	88.35	107.6	213.7
76	Iznik Public H	135	1350	69.55	57.14	110.3	180.75
77	Kagithane Public	51	510	25.71	92.02	26.9	188.61
78	Karacabey Public	168	1680	105.33	62.92	95.5	76.88
79	Karasu Public H	65	650	132.44	166.76	173.3	291.89
80	Kartal Yavuz	105	1050	3.12	69.47	45.91	179.56
81	Keles District H	25	250	111.61	41.16	132.5	119.54
82	Kesan Public H	185	1850	213.51	216.46	171.9	174.24
83	Kirklareli Public	250	2500	187.18	226.45	143.9	243.64
84	Kocaeli Derince	385	3850	56.16	82.49	100.8	207.54
85	Kocaeli Public H	200	2000	66.18	91.11	110.9	216.36
86	Kocaeli	75	750	43.21	62.99	86.41	187.33
87	Kosuyolu High	465	4650	0.402	72.42	44.16	182.14
88	Luleburgaz	250	2500	160.97	192.26	116.6	204.04
89	Lutfiye Nuri	75	750	32.81	94.69	18.03	183.6
90	Marmara Univ	600	6000	7.93	70.4	52.78	183.35
91	Mehmet Akif	260	2600	35.95	88.98	9.22	174.32
92	Muratli Public H	40	400	143.93	166.6	99.6	175.81
93	Mustafa Kemal	252	2520	120.2	66.45	114	61.67
94	Namik Kemal	220	2200	134.08	150.29	91.08	155.9
95	Okmeydani T&R	1000	20000	23.72	89.09	26.17	185.89
96	Orhaneli Public	50	500	112.94	40.59	127.2	99.66
97	Orhangazi Public	110	1100	47.73	31.32	79.62	154.98
98	Osmaneli Public	10	100	93.16	78.94	135.8	198.49
99	Osmangazi	217	2170	80.57	9.27	96.48	116.5
100	Pamukova	20	200	96.27	96.72	140.3	218.95
101	Pasabahce Public	453	4530	23.33	94.45	37.48	196.58
102	Pazaryeri District	10	100	118.67	75.68	154.5	177.36
103	Pendik Public H	100	1000	6.18	68.86	50.14	181.14
104	Pinarhisar Public	25	250	159.84	201.45	117.3	227.48
105	Prof. Mazhar	100	1000	27.6	82.67	16.96	174.2
106	Prof. Turkan	200	2000	82.28	10.38	101.4	122.04
107	Saray Public H	75	750	119.5	162.45	76.85	203.32
108	Sariyer Ismail	120	1200	29.92	100.26	36.16	199.23
109	Savastepe Public	25	250	213.45	155.66	202.2	31.99
110	Silivri Public H	50	500	79.83	114.28	35.51	164.34
111	SSK Pasabahce	453	4530	23.34	94.46	37.43	195.84
112	Sultanbeyli	150	1500	9.32	79.04	50.5	190.28
113	Susurluk Public	50	500	140.56	87.74	131.6	40.93
114	Suleymaniye	120	1200	23.74	82.16	21	177.02
115	Sureyya Pasa	503	10060	4.82	76.15	40.6	182.71
116	Sarkoy Public H	50	500	177.4	171.57	139.6	130.25
117	Sile Public H	50	500	46.82	109.76	81.24	227.5
118	Sisli Etfal	600	12000	22.19	88.19	27.24	185.85
119	Tekirdag Public	400	4000	139.7	154.7	96.79	156.41
120	Toyotasa	100	1000	103.72	120.03	147.9	244.44
121	Trakya Univ	102	31260	228.91	258.38	184.6	249.12
122	Uzunkopru	200	2000	211.99	230.11	168.1	209.89
123	Umraniye	836	16720	14.4	84.99	36.35	188.44
124	Uskudar Public	130	1300	15.99	83.19	31.15	114.57
125	Uskudar Public	18	180	17.81	83.83	28.87	187.57
126	Validebag	100	1000	15.48	82.9	31.62	184.12
127	Vize Public H	30	300	139.17	182.92	97.23	218.69
128	Yakacik	100	1000	3.72	73.29	47.96	183.36
129	Yalova Public H	310	3100	30.17	47.78	67.39	167.58
130	Yedikule Chest	200	2000	23.83	83	21.09	177.26

131	Yeditepe Univ	190	1900	21.14	88.3	29.23	187.39
132	Yeldegirmeni	26	260	15.05	80.76	30.56	181.47
133	Yenikent Public	250	2500	98.63	124.72	142.6	250.25
134	Yenisehir Public	75	750	82.49	48.33	118.8	167.15
135	Zeynep Kamil	200	2000	16.8	83.25	30.05	183.16
136	Zeytinburnu	120	1200	24.1	81.34	20.38	176.23
137	Zubeyde Hanim	688	13760	79.7	8.64	96.33	117.35
	Total	3256	50154				

The amount of blood collected for in 2016 in BDCs in Marmara region and distances between blood donation centers=BDC and regional blood centers=RBC in (km) are given in Table VII.

TABLE VII: Blood Donation Number in Marmara Region (unit) and Distances between Blood Donation Centers=BDC and regional blood centers=RBC, (km).

No	BDC	BDC (Unit)	RBC 1	RBC 2	RBC3	RBC4
1	Kartal	57900	0	72.47	33	181.38
2	Capa	117909	23.17	84.06	9.84	180.45
3	Zeynep Kamil	47627	16.59	83.53	17.48	184.02
4	Cekmekoy	18036	13.18	85.29	34.19	194.66
5	Basaksehir	58992	33	90.24	0	179.26
6	Bursa	72715	81.92	9.47	99	118.75
7	Kocaeli	38817	68.64	93.26	100.88	218.76
8	Sakarya	24942	102.71	123.47	134.52	248.47
9	Balikesir	32768	177.89	122.54	175.26	4.41
10	Canakkale	18886	249.3	227.96	228.63	141
11	Yalova	11138	29.31	45.41	56.36	163.12
12	Corlu	31077	118.17	146.38	86.68	172.75
13	Luleburgaz	13101	161.86	192.81	128.7	204.03
14	Edirne	17452	234.26	263.35	201.41	255.43
	Total	561360				

The number of blood donations in Marmara Region for year 2016 is given in Table VIII.

TABLE VIII: Number of Monthly Blood Donations for BDC's in Marmara Region (unit)

Location	ZeynepKamil	Kartal	Corlu	Luleburgaz	Edirne	Basaksehir	Capa
Jan	3191	5484	2249	889	1120	3796	9213
Feb	4646	5687	2556	1135	1353	4370	8.653
Mar	4362	5295	2911	1470	1744	5020	9325
Apr	4916	6728	3029	1140	1711	6083	10579
May	4037	5259	2979	1181	1659	4982	10446
Jun	2845	3526	1879	902	1237	4672	9772
Jul	3501	4006	2497	783	1222	4749	11153
Aug	3893	4110	2693	1011	1258	4859	9227
Sep	3268	3768	2282	939	1272	3926	8810
Nov	4630	4718	2727	1247	1643	5688	11000
Oct	4347	4859	2742	1273	1425	5362	9344
Dec	3991	4460	2533	1131	1808	5485	10387
Total	47627	57900	31077	13101	17452	58992	117909

	Total	Yalova	Canakkale	Balikesir	Bursa	Izmit	Sakarya	Cekmekoy *
	40400	579	1119	2325	5.132	3.303	2	0
	46125	965	1996	2862	6532	3.334	2.036	0
	49275	1196	1895	3400	6625	3.66	2.372	0
	53751	1179	1717	3634	6581	3.753	2.364	337
	52505	1007	2291	3200	7220	3.498	2.286	2.46
	37772	911	808	2284	3083	2.48	1.25	2.123
	46070	837	1139	2488	5799	3.468	2.371	2.057
	45095	919	1810	2561	6130	2.791	1.919	1.914
	39467	807	1067	1965	5449	2.503	1.657	1.754
	51750	1013	1686	2591	6083	3.612	2.548	2.564
	49890	958	1893	3005	7095	3.077	2.133	2.377
	49260	767	1465	2453	6986	3.338	2.006	2.45
	561360	11138	18886	32768	72715	38.82	24.942	18.036

* In April of 2017, Cekmekoy BDC. has started to blood collection

The amount of blood products; erythrocyte, plasma, and platelet destroyed in 2016 in the Turkish Red Crescent Marmara Region is given in Table IX [6].

TABLE IX: Amount of Blood Discharged (unit)

No	BDC	Erythrocyte	Plasma	Platelets	Total
1	Kartal	911	11304	3899	16114
2	Z Kamil	665	9227	2563	12455
3	Cekmekoy	313	2985	10	3308
4	Basaksehir	1044	18288	1456	20788
5	Capa	1858	32209	5581	39648
6	Bursa	1133	15318	13415	29866
7	Izmit	656	8981	4276	13913
8	Balikesir	509	5520	2046	8075
9	Sakarya	450	6009	2944	9403
10	Corlu	553	8579	1016	10148
11	Canakkale	327	2680	829	3836
12	Edirne	318	4685	518	5521
13	Luleburgaz	224	4598	469	5291
14	Yalova	217	1795	587	2599
Total		9178	132178	39609	180965

Capacity and cost analysis for new distribution centers are given in Table X with some changes [7].

TABLE X: CAPACITY AND COST ($) ANALYSIS FOR THE NEW RBC CENTER. U=UNIT

1 Personel								
		1 month		3 shifts	8 employee	1 responsible	Mothly cost	Yearly cost
					2560	700	3260	39120
2 Depreciation								
10 years of use	72 U	120 U	294 U	504 U	588 U	624 U	798 U	1008 U
Erythrocyte cabinet	1420	1708	2520	4170	5040	5878	6690	8340
Cost per year	142	171	252	417	504	588	669	834
10 years of use	150 U	300 U	450 U	600 U	750 U	900 U		
Platelet locker	3000	5140	6000	8140	9000	45000		
Cost per year	300	514	600	814	900	4500		
10 years of use	490 U	980 U	1470 U					
Plasma cabinet	2460	4920	7380					
Cost per year	246	492	738					
3 Electrical cabinets, cost is $20 per L								
	72 U-160 L	120 U -303 L	294 U -630 L	504U1090 L	588 U-260L	624 U-394L	798 U -720L	1008U-2180L
Erythrocyte cabinet	560	1144	2196	4320	5040	5576	6588	8640
	140 L	286 L	549 L	1080 L	1372.5 L	1440 L	1647 L	2160 L
	150 U -150L	300 U -270 L	450 U -420 L	600 U -540 L	750 U -690L	900 U -810L		
Platelet locker	596	1144	1736	2160	2760	3240		
	149 L	286 L	434 L	572 L	690 L	810 L		
	490 U -455L	980 U	1470 U					
Plasma cabinet	1812	3624	5436					
	453 L	906 L	1359 L					
Rent + Maintenance Fee								
Monthly							4000	4800

The model was solved using GAMS 23.5 software. According to the obtained results the amounts of blood sent from BDC i to RBC j are given in Table XI.

TABLE XI: THE AMOUNT OF BLOOD (UNITS) SENT FROM BDC I TO RBC J

BDC	RBC1	RBC2	RBC3	RBC4
Kartal	57900			
Capa			117909	
Zeynep Kamil	47627			
Cekmekoy	18036			
Basaksehir			58992	
Bursa		72715		
Izmit	38817			
Sakarya	22205.53	2736.474		
Balikesir				32768
Canakkale				18886
Yalova		11138		
Corlu			31077	
Luleburgaz			13101	
Edirne			17452	

The amount of blood delivered to any k hospital from any RBC j was obtained as in Table XII.

TABLE XII: THE ARRANGEMENT OF CHANNELS THE AMOUNT OF BLOOD SENT TO THE HOSPITAL K FROM I RBC (UNIT)

No	Hospital Name	No.of beds	Unit of blood	RBC1	RBC2	RBC3	RBC4
1	Akyazi Public H	100	1000	122.48	135.16	167.1	257.69
2	Alemdag Muhittin	25	250	14.3	86.42	47.58	194.64
3	Arnavutkoy Public H	201	2010	46.32	105.09	17.69	188.73
4	Ayvacik Public H	35	350	276.52	239.31	248.7	126.38
5	Ayvalik Public H	102	1020	274.73	230	251.6	106.78
6	Babaeski Public H	100	1000	186.23	214.23	142.1	216.26
7	Bagcilar T&R H	438	4380	28.61	86.63	17.08	177.87
8	Bakirkoy Dr. Sadi	150	1500	27.5	82.79	17.06	175.47
9	Balikesir Military H	100	1000	179.32	124.13	168	3.93
10	Balikesir Ataturk	900	18000	181.45	125.15	170.3	0
11	Balikesir Public H	400	4000	177.64	122.31	166.7	4.71
12	Balikesir Chest	100	1000	180.43	124.76	169.6	2.17
13	Balikesir Maternity	200	2000	179.3	123.87	168.1	3.32
14	Balya District H	30	300	187.57	140.41	169.8	30.71
15	Bandirma Public H	300	3000	122.83	98	98.7	81.27
16	Basaksehir Public H	100	1000	38.17	97.34	15.42	185.72
17	Bayrampasa Public	300	3000	26.91	87.38	19.72	180.04
18	Besiktas Sait Ciftci	50	500	20.71	87.43	28.68	186.36
19	Beyoglu Eye T&R H	102	1020	20.9	84.67	25.64	181.44
20	Biga Public H	125	1250	178.1	154.38	147.1	88.72
21	Bigadic Public H	75	750	190.71	127.11	186.8	31.11
22	Bilecik Public H	100	1000	110.68	77.68	149.6	187.31
23	Bozuyuk Public H	150	1500	135.4	93.15	172.1	189.36
24	Burhaniye Public H	75	750	244.1	199.25	221.6	79.26
25	Bursa Public H	150	1500	81.7	9.4	99.5	117.76
26	Bursa Dortcelik	350	3500	80.49	14.95	92.56	111.23
27	Bursa Muammer	128	1280	54.62	18.5	78.88	140.83
28	Bursa Mudanya	100	1000	69.17	14.47	81.25	118.67
29	Bursa Sevket Yilmaz	1301	39030	81.44	10.2	101.8	123.32
30	Buyuk Orhan Public	10	100	129.41	57.47	141.6	86.95
31	Buyukcekmece	50	500	47.84	91.63	7.31	167.69
32	Camlica Military	50	500	14.44	82.25	32.52	183.75
33	Can Public H	100	1000	204.5	174.45	175.7	84.26
34	Canakkale 18 March	235	2350	252.53	229.56	218	138.78
35	Canakkale Public H	100	1000	249.02	227.61	214.4	140.05
36	Catalca Ilyas Cokay	75	750	64.36	109.59	20.69	176.46
37	Cekirge Public H	525	10500	80.41	9.25	97.21	116.31
38	Cerkezkoy Public H	200	2000	105.88	145	62.06	185.71
39	Corlu Military H	600	12000	117.87	146.12	73.58	172.28
40	Corlu Public H	400	4000	114.94	142.99	70.37	170.34
41	Darica Farabi Public	350	3500	25.21	62.23	68.58	181.94
42	Dr. Lutfi Kirdar	706	14120	0.288	72.48	44.23	181.12
43	Dr. Siyami Ersek	525	10500	16.08	82	29.96	182.77
44	Dursunbey Public H	75	750	154.23	84.41	159.8	63.45

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45	Edirne Public H	49	4090	230.02	258.63	185.5	252.31
46	Edremit Public H	200	2000	234.46	190.27	212.1	72.82
47	Enez Public H	10	100	260.92	259.61	218.1	198.63
48	Erenkoy Physical	101	1010	10.15	78.6	35.51	182.43
49	Erenkoy Spirit and	250	2500	9.91	78.63	35.78	182.17
50	Esenyurt Public H	200	2000	44.4	91.61	13.9	172.26
51	Eyup Public H	100	1000	25.28	88.59	23.12	183.55
52	Ezine Public H	100	1000	270.93	238.7	241	133.33
53	Gaziosmanpasa	300	3000	30.05	92.35	20.28	185.58
54	Gebze Fatih Public	400	4000	24.71	64.74	68.48	184.61
55	Geyve Public H	40	400	103.96	106.71	148.9	228.89
56	Golcuk Public H	171	1710	60.59	80.39	104.8	205.17
57	Gonen Public H	90	900	155.76	120.86	132.8	57.49
58	Goztepe T&R H	660	13200	12.66	79.72	33.08	182.32
59	Gumussuyu Military	300	3000	20.63	85.88	26.97	184.09
60	Haseki T&R H	206	2060	22.11	83.32	23.28	179.78
61	Haydarpasa Numune	709	14180	16.03	82.02	30.52	181.55
62	Hayrabolu Public H	50	500	177.2	197.47	132.5	189.51
63	Hendek Public H	100	1000	130.98	149.28	175.3	272.86
64	Inegol Public H	332	3320	96.62	40.85	126.9	146.88
65	Ipsala Public H	50	500	234.6	239	192.3	194.17
66	Istanbul T&R H	560	11200	22.24	82.67	22.8	178.42
67	Istanbul Physical	263	2630	29.63	84.5	15.12	175.4
68	Istanbul Kanuni	648	12960	38.25	91.65	8.17	177.08
69	Istanbul	52	520	4.82	75.88	40.52	182.69
70	Istanbul Univ	1042	31260	22.16	82.74	23.01	179.19
71	Istanbul University	840	16800	23.33	84.17	22.22	180.8
72	Istinye Public H	100	1000	24.31	94.23	33.83	194.05
73	Ivrindi Public H	36	360	205.44	155.12	188.6	33.88
74	Izmit Women's	520	10400	69.85	95.55	114.3	221.28
75	Izmit SEKA Public	75	750	63.2	88.35	107.6	213.7
76	Iznik Public H	135	1350	69.55	57.14	110.3	180.75
77	Kagithane Public H	51	510	25.71	92.02	26.9	188.61
78	Karacabey Public H	168	1680	105.33	62.92	95.5	76.88
79	Karasu Public H	65	650	132.44	166.76	173.3	291.89
80	Kartal Yavuz Selim	105	1050	3.12	69.47	45.91	179.56
81	Keles District H	25	250	111.61	41.16	132.5	119.54
82	Kesan Public H	185	1850	213.51	216.46	171.9	174.24
83	Kirklareli Public H	250	2500	187.18	226.45	143.9	243.64
84	Kocaeli Derince	385	3850	56.16	82.49	100.8	207.54
85	Kocaeli Public H	200	2000	66.18	91.11	110.9	216.36
86	Kocaeli Karamursel	75	750	43.21	62.99	86.41	187.33
87	Kosuyolu High H	465	4650	0.402	72.42	44.16	182.14
88	Luleburgaz Public H	250	2500	160.97	192.26	116.6	204.04
89	Lutfiye Nuri Borat	75	750	32.81	94.69	18.03	183.6
90	Marmara Univ	600	6000	7.93	70.4	52.78	183.35
91	Mehmet Akif Ersoy	260	2600	35.95	88.98	9.22	174.32
92	Muratli Public H	40	400	143.93	166.6	99.6	175.81
93	Mustafa Kemal Pasa	252	2520	120.2	66.45	114	61.67
94	Namik Kemal Univ	220	2200	134.08	150.29	91.08	155.9
95	Okmeydani T&R H	1000	20000	23.72	89.09	26.17	185.89
96	Orhaneli Public H	50	500	112.94	40.59	127.2	99.66
97	Orhangazi Public H	110	1100	47.73	31.32	79.62	154.98
98	Osmaneli Public H	10	100	93.16	78.94	135.8	198.49
99	Osmangazi Military	217	2170	80.57	9.27	96.48	116.5
10	Pamukova PublicH	20	200	96.27	96.72	140.3	218.95
10	Pasabahce Public H	453	4530	23.33	94.45	37.48	196.58
10	Pazaryeri District H	10	100	118.67	75.68	154.5	177.36
10	Pendik Public H	100	1000	6.18	68.86	50.14	181.14
10	Pinarhisar Public H	25	250	159.84	201.45	117.3	227.48
10	Prof. Mazhar Osman	100	1000	27.6	82.67	16.96	174.2
10	Prof. Turkan Akyol	200	2000	82.28	10.38	101.4	122.04
10	Saray Public H	75	750	119.5	162.45	76.85	203.32
10	Sariyer Ismail Akgun	120	1200	29.92	100.26	36.16	199.23
10	Savastepe Public H	25	250	213.45	155.66	202.2	31.99
11	Silivri Public H	50	500	79.83	114.28	35.51	164.34
11	SSK Pasabahce	453	4530	23.34	94.46	37.43	195.84
11	Sultanbeyli Public H	150	1500	9.32	79.04	50.5	190.28
11	Susurluk Public H	50	500	140.56	87.74	131.6	40.93
11	Suleymaniye	120	1200	23.74	82.16	21	177.02
11	Sureyya Pasa Chest	503	10060	4.82	76.15	40.6	182.71
11	Sarkoy Public H	50	500	177.4	171.57	139.6	130.25
11	Sile Public H	50	500	46.82	109.76	81.24	227.5
11	Sisli Etfal	600	12000	22.19	88.19	27.24	185.85
11	Tekirdag Public H	400	4000	139.7	154.7	96.79	156.41
12	Toyotasa Emergency	100	1000	103.72	120.03	147.9	244.44
12	Trakya Univ Health	102	31260	228.91	258.38	184.6	249.12
12	Uzunkopru Public H	200	2000	211.99	230.11	168.1	209.89
12	Umraniye	836	16720	14.4	84.99	36.35	188.44
12	Uskudar Public H	130	1300	15.99	83.19	31.15	114.57
12	Uskudar Public H	18	180	17.81	83.83	28.87	187.57
12	Validebag Teachers	100	1000	15.48	82.9	31.62	184.12
12	Vize Public H	30	300	139.17	182.92	97.23	218.69
12	Yakacik Women's	100	1000	3.72	73.29	47.96	183.36
12	Yalova Public H	310	3100	30.17	47.78	67.39	167.58
13	Yedikule Chest	200	2000	23.83	83	21.09	177.26
13	Yeditepe Univ Eye	190	1900	21.14	88.3	29.23	187.39
13	Yeldegirmeni	26	260	15.05	80.76	30.56	181.47
13	Yenikent Public H	250	2500	98.63	124.72	142.6	250.25
13	Yenisehir Public H	75	750	82.49	48.33	118.8	167.15
13	Zeynep Kamil	200	2000	16.8	83.25	30.05	183.16
13	Zeytinburnu T&R H	120	1200	24.1	81.34	20.38	176.23
13	Zubeyde Hanim	688	13760	79.7	8.64	96.33	117.35
	Total	3256	50154				

V. Conclusion

In this study, a blood supply chain network design such as Blood Donation Centers (BDC), Regional Blood Centers (RBC), Destruction Centers (DC), and hospitals (H) were considered. According to the GAMS software version 23.5, the Mixed Integer Model was found to be suitable and formulated for the problem.

When the number of RBCs in Marmara region were reduced from 3 to 2 the opening and transportation costs increased to $5.37 million. When the number of BDCs was increased from 3 to 4 the opening and transportation costs fell to $3.94 million if the existing 3 RBCs remain the same the opening and transportation costs will increase to $4.76 million.

It is possible to add 1 more RBC to the existing RBCs in the region and add 1 destruction center to the destruction centers thus minimizing the distance between RBCs and hospitals and eliminating the blood products that cannot be used in the existing supply chain without damaging the environment and human health. With the proposed model it has been seen that blood donation centers have access to regional blood centers and transportation costs from regional blood centers to hospitals can be minimized.

Symbols and Abbreviations List

BDC: Blood Donation Center

RBC: Regional Blood Center

DC: Destruction Center

i: BDC index

j: indicates the potential RBC approved by the decision maker.

k: integrated cluster index of potential RBC and hospitals.

m: Indicates the index of DC.

The parameters used are given below.

bij: Distance between potential RBC j and BDC i

djk: Distance between RBC and hospitals

q: Transportation cost per kilometer ($/km)

fj: Opening cost for j RBC ($/year)

am: DC opening cost

rjm: Distance between RBC j and DC m

gjm: The amount to be transported between RBC j and DC m (unit)

hjk: The amount to be transported between RBC j and hospital k (unit)

vij: The amount to be moved between BDC i and RBC j (units)

Uk: Hospital demands

Ti: The sum of the amount of blood collected for the products

kapj: Capacity of RBC's

Wm: Capacity of DC

α: destruction rate (5%)

Decision Variables are as follows:

0-1 Variables:
Xj: 1 if opened in RBC j, otherwise 0.
Zm: 1 if opened in DC m, otherwise 0.

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