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Investigation of single and double cross-match processes and their costing using material flow cost accounting technique

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ABSTRACT

Cross-match is a very key stage in the blood supply chain distribution phase. In the single cross-match, the blood product is reserved for each applicant for the required number of blood bags, and if the blood products are taken out of the blood bank and not used, they are discarded and the environmental effects and costs seek out the hidden ones. Attention is also paid to the social phenomena that affect blood donation and collection. For example, in the pandemic caused by COVID-19, blood donation in Iran decreased by an average of 30 to 40 percent. In this study, a double cross-match process is introduced in which instead of a single cross-match being given to a patient applying for a bag of blood products, two bags of cross-matching blood products are introduced to two patients. The main question in this study is that because, in the double cross-match operation, the crossmatch process for a patient is repeated twice, whether the combined costs of manpower, energy, raw materials, and waste economically justify the double cross-matching process for replacement with the current conventional cross-match in the hospital blood bank. To investigate this issue, the material flow costing accounting technique has been used. It has been shown that this method can reduce the loss of blood products and increase the likelihood of consuming long-lived blood. Numerical results show that the probability of consuming blood products increases from 50 to 75% and manpower costs from 37 to 50%.

Keywords:

Single Cross-match, Double Cross-match, Material Flow Cost Accounting, Environmental effects, COVID-19.

1. Introduction

Hospitals transfuse blood products to those injured in accidents, patients who require organ transplants, and patients with leukemia or other diseases. There is always a demand for blood products, and definitely, this demand cannot be determined in advance. Therefore, having a blood bank system with a sufficient supply of fresh blood is one of the key components of all health systems in the world (Negroni et al., 2012). According to a report by the US Red Cross, in normal conditions, one blood transfusion service is needed every two seconds. In the USA, blood transfusion centers require more than 39,000 donors every day, and most reports announce that the blood supply will be used up in 2 days. In 2012, the US blood inventory reached its lowest level in 15 years (Goldfarb, 2013). In Iran, every three seconds a patient needs blood or blood products. The Blood Transfusion Organization also tries to provide sufficient supplies for normal and emergencies. Each blood transfusion center in Iran must have blood inventory for at least five days. Therefore, blood availability is one of the key requirements of this organization.

Inventory management, availability, and preventing waste resulting from reaching the expiration date are the main challenges with perishable products (Nahmias, 2011). Since blood is a perishable product, blood inventory management is a subset of the issue of perishable inventory. Nahmias claimed that the researchers' interest in and motivation for perishable inventory issues initially sparked the issue of blood bank management. On the one hand, a shortage of blood inventory is unthinkable for a patient who is in urgent need of blood, and on the other hand, having excessive quantities of blood results in unnecessary costs to the health system (Stinger et al., 2012). Therefore, the challenge of pursuing two goals, i.e. maintaining the optimal level of inventory to prevent blood shortage and minimizing waste, has always been a concern for blood transfusion organizations.

The key point in the blood supply chain as a service is cost management. The cost of blood, in general, depends on the steps that have to be taken for delivering the blood unit. The more complex these steps are, the more expensive the service will be. (Schander et al., 2007). The cost for a unit of red blood cells in the United States increased by 6.4% between 2005 and 2007, which increases the necessity of paying more attention to proper blood consumption. In many countries, hospitals pay 90% of the loss cost of the expired blood, resulting in the highest stress and cost pressure for hospitals (Chen, 2010). The crossmatching stage is an important step in the blood supply chain in cost management. At this stage, a patient's blood sample is cross-matched with the blood donated to the hospital's blood bank. Since the crossmatching process is done after a doctor's order, if the crossmatched blood bag is not removed from the hospital's blood bank and the physician does not use the blood product, the blood bag can be used for future cross matchings. However, if the cross-matched blood product is removed from the hospital's blood bank, it should be discarded if not used. This leads to the wastage of blood products and environmental issues. Of course, blood products may also reach their expiration date before cross-matching. In both cases, the cost of wasted blood products is incurred on the hospital's blood bank and the hospital is exposed to environmental dangers resulting from the disposal of blood products.

One of the strategies suggested for increasing the likelihood of consuming cross-matched blood products and reducing the number of expired blood products is to use a secondary cross-matching process (Gonpinar,2015). In secondary cross-matching, instead of providing one recipient with a cross-matched bag, two blood product bags are cross-matched for two patients. To illustrate the process of secondary crossmatching, an example of a hospital blood bank is given. Suppose that the planning period for the hospital blood bank is 7 days, the first inventory at the beginning of the period includes 15 blood bags and no purchase will be made till the end of the period. As described in Table (1), a total of 5 patients will receive the blood transfusion service during the period:

Table (1): Information on Patients Needing Blood Products

day of use/cancellation	Demand amount	Reserved Amount	entry Day	Patient code
3 /cancelled	3	2	1	A
1 / used	2	1	1	B
2 /used	3	2	1	C
3 / cancelled	1	2	3	D
6 /used	3	3	4	E

The main research question is: Because in secondary cross-matching process, cross-matching is repeated twice for one patient, can the sum of the different costs of manpower, energy, materials, and wastage justify the process of secondary crossmatching economically, and make it replace the conventional cross-matching in hospitals' blood banks? To investigate this issue, the Material Flow Costing Accounting technique (MFCA) was used.

The rest of the paper includes the following sections: Section two deals with cross-matching literature on blood products and material flow costing techniques. The next section presents the research methodology. In the Results section, a case study is carried out and the costs of the primary and secondary cross-matching are compared. Finally, in the last section of the paper, the conclusions and the future research suggestions are discussed.

Blood Life During the Planning Period							allocation													
							1		2		3		4		5		6		7	
1	2	3	4	5	6	2	P	S	P	S	P	S	P	S	P	S	P	S	P	S
28							A	B												
28							A	B												
28	29						A	C	A	C										
27	28						C		C											
23	24						C		C											
22	23	24	25	26	27						D		D	E	E		E			
19	20	21	22	23	24								E		E		E			
19	20	21	22	23	24								E		E		E			
19	20	21	22	23	24															
14	15	16	17	18	19	19														
12	13	14	15	16	17	18														
12	13	14	15	16	17	18														
10	11	12	13	14	15	16	C	A	C	A										
9	10	11	12	13	14	15	B	A	A											
3	4	5	6	7	8	9	B	A	A				E	D						

The age composition of the first inventory of blood products in the period is described in Table (2).

Table (2): Age composition of the hospital's blood bank inventory

22	22	23	22	19	14	12	11	9	3	age
3	1	1	1	3	1	2	1	1	1	number

As outlined in Table (3), the 7-day planning table is proposed according to the secondary cross-matching process. For example, in the first allocation for Patient A who needs three blood product bags, three primary blood bags, and three secondary bags are cross-matched. Patient B who needs two blood bags, two primary blood bags, and two secondary blood bags are cross-matched. The patient consumes a bag on the first day.

Table (3): Blood bags Allocation based on Secondary Cross-matching

2. Literature Review

Many tools including quality standards, comprehensive quality management systems, comprehensive production maintenance systems, and on-time production plans are used to improve productivity, but none of these commonly mentioned systems can take into account the cost of wastage control. Material flow cost accounting in a standard and powerful method for reducing adverse environmental effects, improving productivity, and reducing costs as well as improving energy efficiency. This method concentrates on wastage and seeks the transparency of the values for gain and loss.

The concept of material flow cost, which later emerged in 14051 ISO standard, came into being as a result of environmental management projects implemented in Kunert textile factory in the late 1980s and early 1990s in southern Germany. In 1999, Japan's Ministry of Economy, Trade, and Industry (METI) started the environmental management accounting project. Then, as a METI pilot project, the material flow cost was introduced to Nitto, Denko, Canon, Tanabe, Seiyaku, and Takiron companies. In 2007, METI started to develop a new ISO standard for MFCA in the 14000 ISO family in the field of environmental management, which after being discussed in 28 national committees across the world, was published in 2011 as "ISO 14051" (Wagner, 2015).

In a paper published in 2015, Schmidt presented a mathematical algorithm for the distribution of costs in production systems for both products and wastages. The basis of this algorithm is the physical quantity structure of material and energy flows in a production system. These physical quantities can later be used to account for the financial values or environmental effects. From an economic point of view, MFCA output is well known, and from an environmental viewpoint, the environmental effects which can be controlled by reducing wastage can be calculated. This process can also be used to analyze the domestic recycling flows and their potential for economic and environmental improvements. This feature allows companies to make decisions about the criteria related to material flow and helps reduce costs and environmental impact (Schmidt, 2015). This technique is used in many production and nonproduction environments. Table 4 classifies the research on this technique according to the following criteria:

A) According to the purposes of using material flow cost accounting which is mentioned below: ➢ Improved efficiency;
   - ➢ Reduction in the amount of waste;
   - ➢ Reduction in other manufacturing costs (e.g. waste handling, treatment, and associated infrastructure costs);
   - ➢ More accurate product costing;
   - ➢ Incentives for innovation;
   - ➢ Improved inter-departmental communication concerning resource use;
   - ➢ Improved management control.

B) According to the usage of material flow cost accounting in each research. The usages are categorized as follows: ➢ Low engagement in practice;
   - ➢ Case-based research; ➢ Developing economies; ➢ Supply chain management tool.

Table 4: A comparison of the studies conducted in the field of MFCA

Reference	Applications				Goals							Case study
	practice	Case based research low engagement in	economies	management tool	Improved efficiency	amount of waste	reduction in other manufacturing costs reduction in the	accurate product costing	Incentives for innovation	Improved management control	departmental communication	Improved inter
(Staniskis and Stasiskiene, 2005)		●				●	●	●				Lithuanian companies
(Kokubu et al., 2005)	●	●								●		companies listed in the first section of the Tokyo Stock Market
(Staniskis and Stasiskiene, 2006)		●				●	●					Lithuanian companies
(Burritt et al., 2009)		●	●		●	●	●					Oliver Enterprises, a rice milling business in the Philippines,
(Jasch et al., 2010)		●				●						an Integrated UNIDO Project in Honduras
(Viere et al., 2011)		●		●	●						●	coffee refining and exporting enterprise in Southern Vietnam
(Schaltegger, 2011)	●	●										large German companies

(Papaspyropoulos et al., 2012)		●									●	a nonprofit forestry organization of Macedonia
(Schaltegger et al., 2012)		●	●		●	●						a major Vietnamese beer producer
(Yagi and Kokubu, 2018)		●				●	●	●				non-financial listed companies in Thailand
(Dunuwila et al., 2018)		●	●		●	●						the crepe rubber production as a case study in Sri Lanka
(Kawalla et al., 2018)		●						●		●		twin-roll casting process
(Zou et al., 2019)		●			●				●			aluminum production
(Yagi and Kokubu, 2019)		●			●	●	●				●	125 Japanese manufacturing firms
(Dekamin and Barmaki, 2019)		●				●	●					soybean production
(Behnami et al., 2019)		●				●		●				a petrochemical wastewater treatment plant
This research		●	●		●	●				●		An Iranian hospital

Based on the research on primary and secondary cross- A. Due to the possibility of the wastage of crossmatching processes, the scientific contribution of the matched blood products in the primary cross-matching present research can be expressed in the following process, secondary cross-matching can be used to items: reduce wastage costs.

Therefore, the present research seeks to use material flow cost accounting to compare different steps of these processes.

B. The previous research in the field of distribution of blood products has made no mention of the secondary cross-matching process. Gunpinar's paper in 2015 has proposed using a secondary crossmatching process for reducing inventory costs.

3. Methodology

3.1. Concepts

In the process of primary cross-matching, one blood bag is cross-matched for the patient who needs a blood bag, but in the process of secondary crossmatching, instead of being cross-matched for one patient, each blood bag is cross-matched for two patients at the same time. In other words, the process of cross-matching is repeated twice for one patient. This difference in the conceptual model of the crossmatching process is shown in Figures 1 and 2, where each stage of the process is defined as a QC and the energy of materials that enter the final QC in the form of wasted material and energy or used product that leaves the QC. In the wasted product, called the negative product, the total input of energy or material is calculated, and the resulting environmental effects are assessed. In this study, for each QC, the cost of material input and output is shown by taking into account a certain amount of energy consumption. values for the positive and negative products resulting Material costs are calculated by multiplying the values from energy consumptions are shown in relationships 1 for the weight of the raw materials and the output to 13. produced by the cost of raw materials during the processes of primary and secondary cross-matchings.

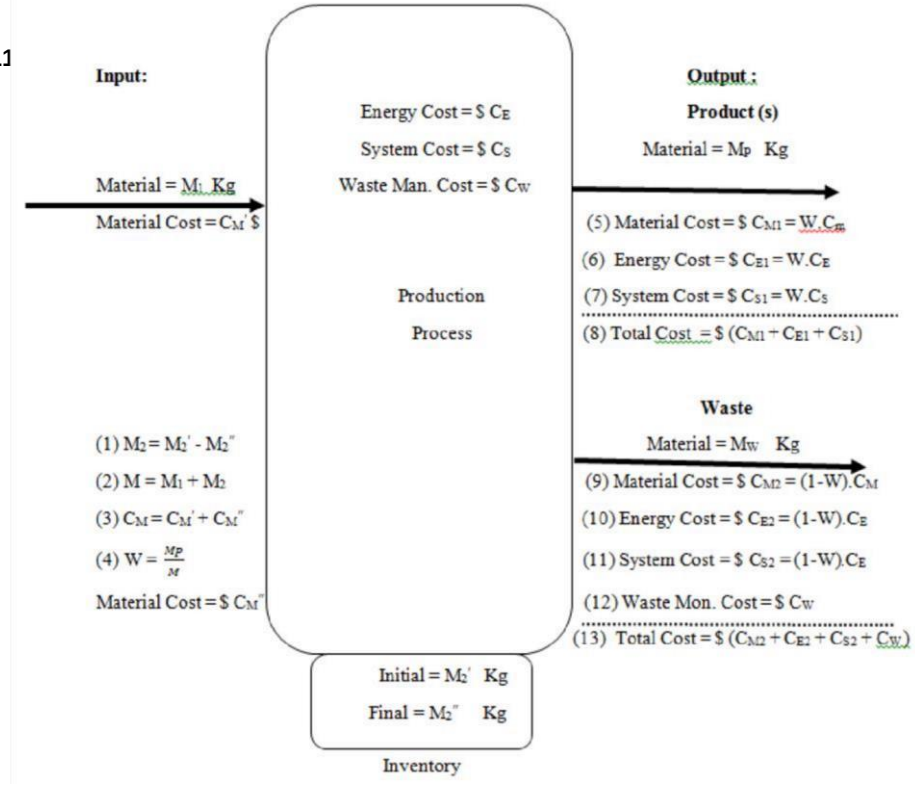

Figure 3: MFCA calculations

Figure 1: The conceptual model of single cross-match

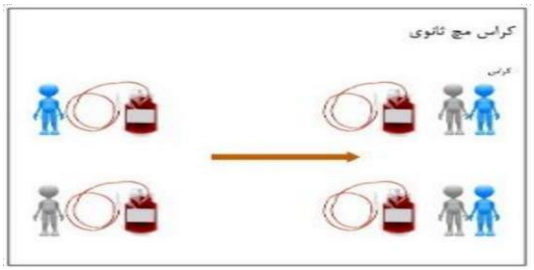

Figure 2: The conceptual model of double cross-match

In this study, for each QC, the costs of materials and the system's output and input are determined. In material flow cost calculations, the total material input, the efficiency of the cross-matching process, and waste values have been considered. In MFCA calculations shown in figure 3, the total material input and energy

3.2. Data analysis

The hospital under study is a hospital in the city of Qom. It is located in an area of approximately 27000 square meters with a built-up area of about 13000

square meters. It has 200 licensed beds and 159 available beds. According to the Ministry of Health's evaluation, the hospital is nationally ranked among the first and has separate departments for open-heart surgery subspecialty, angiography, radiotherapy, maternity, and hydrotherapy.

Like other hospitals, the hospital's blood bank has to provide the blood needed for patients. According to the information obtained from the Hospital's bank Blood in May 2020, the blood bank inventory this month included 193 bags of various blood products. The number of primary crossmatchings was twice for 23 bags, three times for eight bags, and more than three times for two bags. Commonly, blood crossmatching consists of three stages: 1) determining the patient's blood type, 2) confirming the bag's blood type,and 3) doing primary cross-matching; Each stage is defined as a QC.

3.2.1. Determining Patient's Blood Type

The purpose of this step is to determine the person's ABO phenotype according to the presence or absence of antigen A or B at the surface of red blood cells and to determine the Rh (D) of red blood cells as Rh-Positive and Rh-Negative phenotypes considering the presence and absence of antigen D on the surface of the membrane of red blood cells. Table 5 shows the timing of various QC1 activities.

In the above table, the preparation of the 3% red power of agglutination in determining the blood type. blood cell suspension is meant to eliminate the adverse Table 6 shows in detail the timing of the activities for effects of globulin concentration as well as the contents preparing the 3% red blood cell suspension. of plasma (serum) on the sensitivity of the test and the

Table 5: The timing of the determination of the patient's blood type in QC1

Elements	Description of the element	time (minute)
1	Writing the name of the patient and the letters B, A, and D on three 12 x 75 mm test tubes and placing the tubes in the tube rack	0.5
2	Preparing the 3% red blood cell suspension	6.1
3	Putting a drop of the suspension of patient's red blood cells in each of the three test tubes using a sampler and then putting a drop of A-Anti in tube A and a drop of BAnti in tube B and a drop of D-Anti in tube D, shaking the tubes for mixing and then putting them in the centrifuge	0.75
4	centrifuging at 1000 g for one minute	1
5	Removing the tubes from the centrifuge and tapping the tubes gently, Checking for the presence or absence of agglutination in each of the tubes under the light of the lamp with the help of a concave mirror, interpreting and recording the result in the laboratory notebook	1.5
Total time		9.85

Table 6: The timing of the preparation of 3% red blood cell suspension

Elements	Description of the element	time (minute)
1	writing the patient's name on the 10 ml test tube and putting at least one milliliters of whole blood by a sampler in the tube	0.5

8	Removing the tube from the centrifuge, removing the parafilm from the tube, emptying the physiological serum, and cleaning the edge of the tube with sterile gauze	0.25
9	Adding so much saline to the tube that the color gets like the color of pomegranate juice as shown in the standard image sent by the Blood Transfusion Organization (if you mix 0.3 ml of the washed red blood cells with 9.7 ml of 0.9 normal salines, you will get the desired color). Placing the tube containing the suspension in the tube rack	0.15
Total time		6.1
2	Adding 0.9% normal saline to red blood cells and closing the tube with parafilm and then turning the tube upside down several time to mix the red cells with saline and putting the tube in a centrifuge	0.5
3	centrifuging at 1000g for one minute	1
4	Removing the tube from the centrifuge, removing the parafilm from the tube, emptying the physiological serum, cleaning the edge of the tube with sterile gauze, shaking the tube gently, adding saline for the second time, closing the tube with parafilm, turning it upside down several times, and putting it in the centrifuge	0.85
5	centrifuging at 1000g for one minute	1
6	Removing the tube from the centrifuge, removing the parafilm from the tube, emptying the physiological serum, cleaning the edge of the tube with sterile gauze, shaking the tube gently, adding saline for the third time, closing the tube with parafilm, turning it upside down several times, and putting it in the centrifuge	0.85
7	centrifuging at 1000g for one minute	1

After performing QC1, if agglutination is observed in tube A, the blood group is A, if agglutination happens in tube B, the blood group is B, if agglutination happens in both tubes, the blood group is AB, and if agglutination is not observed in any of the tubes, the blood group is O. If agglutination is observed in tube D, it is Rh-positive and otherwise it is Rhnegative.

3.2.2. Timing of the confirmation of blood bag's group

The purpose of the second stage (QC2) is to eliminate the possible error in grouping bags containing red blood cells in the blood transfusion organization and to prevent labeling the wrong blood type on the bags. Table 7 shows the timing of various activities in QC2.

3.2.3. The timing of cross-matching The purpose of with the patient ABO group and diagnose any clinically

Table 7: Timing of the confirmation of the blood bag's group in QC2

Elements	Description of the element	time (minute)
1	Writing the letters A, B, and D on three 12 x 75mm test tubes and putting them is the tube rack	0.45
2	Taking out from the blood bank refrigerator a blood bag with the same type as the patient's blood type, separating a cord from it, marking the bag, and returning it to the refrigerator	0.32
3	Scissoring one side of the cord and putting the blood into a test tube to prepare the suspension	0.32

4	* Preparing the 3% Blood bag suspension	6.1
5	Putting a drop of red blood cell suspension in each of the three test tubes using a sampler, and then putting a drop of A-Anti in tube A, a drop of B-Anti in tube B, and a drop of D-Anti in tube D, Shaking the tubes to mix and then putting them in the centrifuge	0.75
6	centrifuging at 1000g for one minute	1
7	Removing the tubes from the centrifuge, tapping the tubes gently and checking for the presence or absence of agglutination in each of the tubes under the light of the lamp with the help of a concave mirror, interpreting and recording the result in the laboratory notebook	1.5
Total time		10.44

doing QC3 is to perform a major crossmatching test with important unexpected alloantibody.
the patient's serum/ plasma and donor's red blood cell for Table 8 shows the timing of different QC3 activities. the confirmation of the compatibility of blood bag ABO

Table 8: The timing of cross-matching in QC3

Elements	Description of the element	time (minute)
1	Step 1: writing the patient's name on a 12 x 75 mm test tube and putting the tube in the tube rack, then putting 2 drops of the patient's serum or plasma in the tube using a sampler	0.4
2	Putting one drop of blood bag suspension in the tube using a sampler	0.12
3	shaking the tube to mix and then place it in the centrifuge at 1000g for one minute	1.20

4	Taking out the tube from the centrifuge and tapping it gently to release the globulin mass as suspension, checking for agglutination, interpreting and recording the test results	0.5
5	Step 2: adding two drops of LISS to the tube (LISS shortens the time, compared to Albumin, mixing and putting the tube in the incubator for 15 minutes at 75 degrees	15.4
6	Placing the tube in the centrifuge at 1000g for 30 seconds	0.6
7	taking out the tube from the centrifuge and tapping it gently to release globulin mass as suspension, checking for agglutination, interpreting and recording the test results	0.66
8	Step 3: Washing the tube with 0.9% saline three times	3
9	Emptying saline from the tube completely, adding Anti-hymen globulin and mixing, putting in the centrifuge at 1000g for one minute	1.5
10	Taking out the tube from the centrifuge and tapping it gently to release globulin mass as suspension, checking for agglutination, interpreting and recording the test results	0.6
11	Step 4: (if in the last step a negative reaction is observed) adding a drop of sensitized red blood cell (check cell) to the tube	0.12
12	Shaking the tube to mix and then putting it in the centrifuge at 1000g for 30 seconds	0.84
13	taking out the tube from the centrifuge and tapping it gently to release globulin mass as suspension, checking for agglutination, interpreting and recording the test results	0.6
Total time		25.54

4. Results

The calculations show that doing a complete three-step cross-matching operation takes 45.83 minutes. Figures 4 and 5 show the calculations related to material flow cost accounting parametrically shown in figure 3. Moreover, in figures 6 and 7, the share and presented. Charts 1 and 2 show the number of percentage of input and output elements in primary primary and secondary cross-matchings done in the and secondary cross-matching processes is calculated first 15 days of one month.

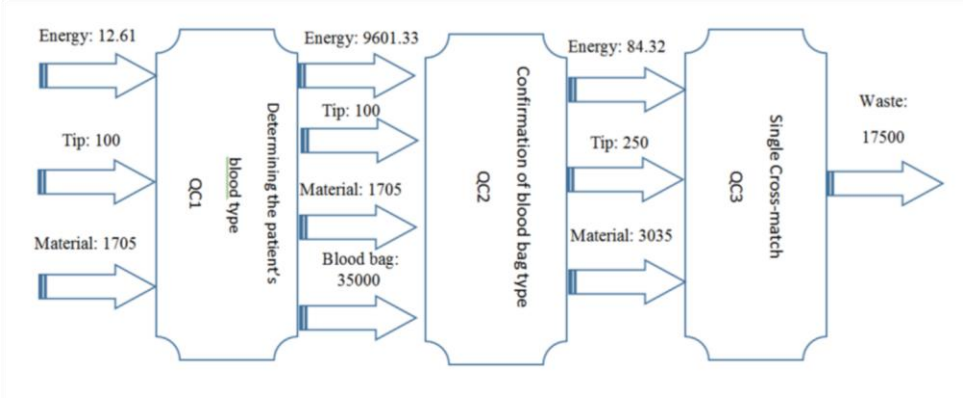

Figure (4): single cross-match MFCA calculations

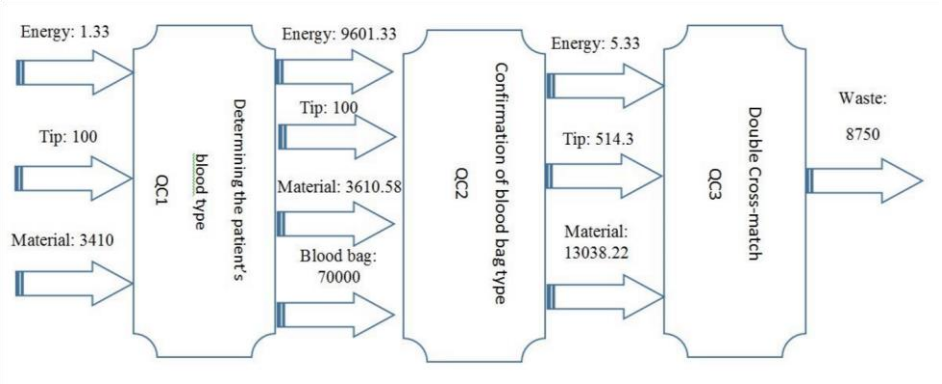

Figure (5): Double cross-match MFCA calculations

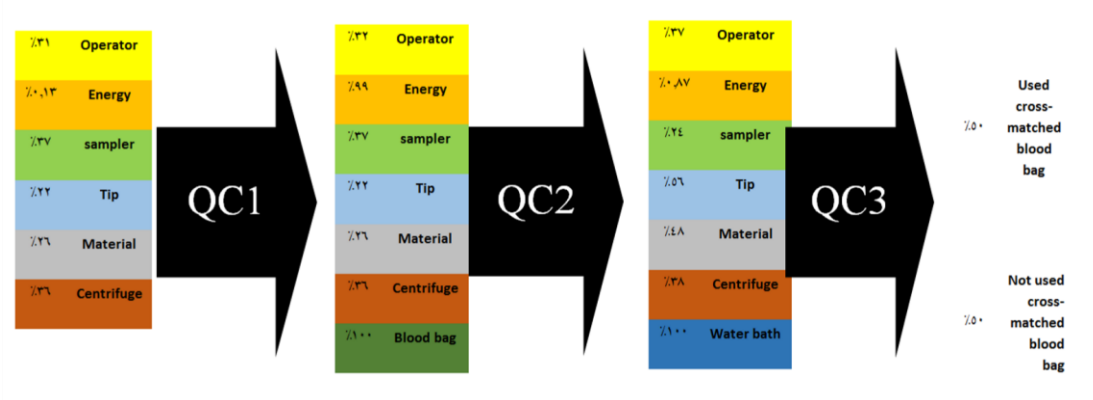

Figure (6): Percentage of input and output elements in the single cross-matching process

As mentioned earlier, one of the most important steps in the blood supply chain is the distribution of blood products, which is done after the stages of blood collection, blood product production, and blood storage. One of the important steps in the stage of blood product distribution is the process of crossmatching that must be done before using blood products. Based on blood transfusion protocols, eliminating this stage is not possible at all.

The cross-matching process in hospitals and medical centers is done to determine if blood products can be used by an intended recipient. If the consumption of cross-matched blood products is not allowed for any reason by the treating physician, the blood product, which is prepared at high costs during

various stages of the blood supply chain, is wasted, and and the blood transfusion network.

Apart from the issue of blood transfusion costs, the social phenomena that affect the donation and collection of blood should also be taken into account. The cross-matching process becomes more necessary when blood donation is considerably reduced. For example, in the pandemic caused by Coronavirus, which led to COVID-19, on average the donation of blood in Iran decreased by 30 to 40 percent. Therefore, in the time of such crises, in addition to the increase in the cost of transfusing blood products, the shortage of blood product supplies severely affects the blood transfusion network and the patients in need of blood products.

Therefore, by introducing a secondary crossmatching process as an alternative to the current crossmatching process, this study tried to reduce the wastage of blood products. This process has been suggested in very few studies and has received little attention in medical centers and hospitals. One of the main concerns in medical centers and, in general, the this can lead to heavy costs to the blood supply chain

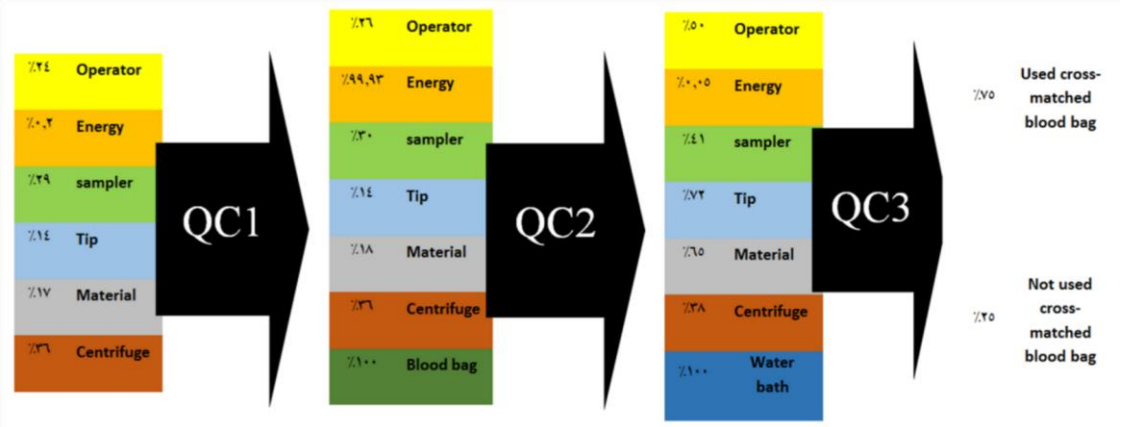

Figure (7): Percentage of input and output elements in the double cross-matching process

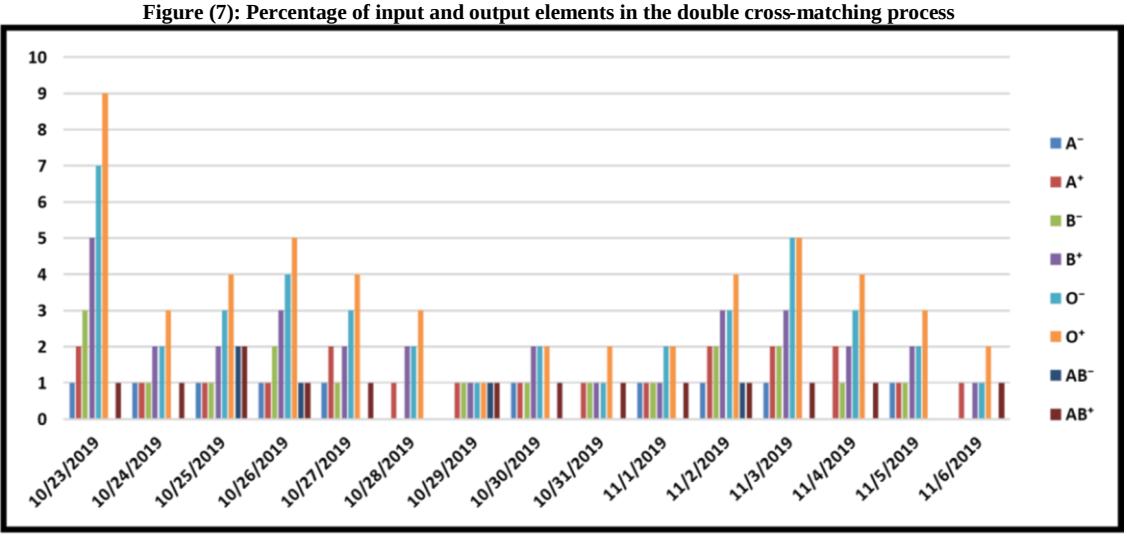

Figure (8): Number of single cross-matches by blood type

5. Discussion and conclusion

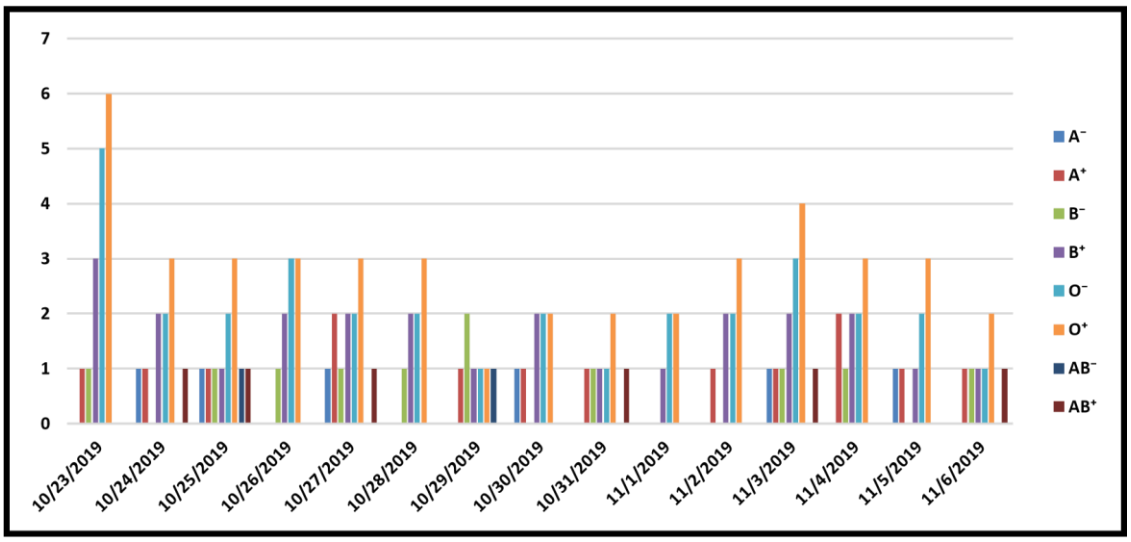

Figure (9): Number of double cross-matches by blood type

blood supply chain is the cost of this process which, if implemented, will be incurred on the distribution system. Using the material flow cost technique, this research calculates and compares the cost components of primary and secondary cross-matching processes. The obtained results are stated in the following paragraphs:

1) In the first and second quality control center)QC1 and QC2), compared to primary cross-matching, manpower, and man-hour costs in secondary cross-matching decrease 7% and 6%, respectively ,which is due to the combination of different operations.
2) In the third quality control center (QC3), compared to primary cross-matching, manpower and man-hour costs in secondary cross-matching increases 13%, which is due to the increase in the time of different operations.
3) In general, for all blood groups, on average, the probability of consuming blood products rises from 50% in primary cross-matching to 75% in secondary cross-matching. But this increase in the probability of consumption and reduction in wastage of a variety of blood products is not the same for all blood groups. In the hospital under study, secondary crossmatching is less different from primary crossmatching in the O blood group compared to other blood groups.
4) The numbers recorded from the case study show that secondary cross-matching for lowfrequency blood groups such as AB can cause more blood wastage than other blood groups.
5) For most blood groups, on average the lifespan of blood products in primary cross-matching at the time of consumption is shorter than the lifespan of blood products in secondary crossmatching. So it can be argued that secondary cross-matching increases the possibility of consuming blood products with a longer lifespan.

The research implications can be summarized in the following items:

1) To this day, the process of primary crossmatching has been able to fulfill different patients' needs for a variety of blood products in all blood groups, but in case of a reduction in blood bank supplies, secondary crossmatching can be used to reduce blood wastage and increase the possibility of consumption of blood products with a long lifespan. So the officials and managers of blood banks in medical centers should take the necessary measures to train the related personnel to implement a secondary cross-matching process.
2) The officials in the blood banks in medical centers should note the point that although secondary cross-matching reduces the wastage of blood products with a long lifespan, due to the complexity of the cross-matching process, the personnel should be given special privilege and encouragement for doing secondary crossmatching.

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