Blood Banks Negotiation Framework

Lívia Rodrigues Barreto (Universidade Federal Rural do Semi-Árido)
liviarodriguesbarreto@gmail.com

Breno Barros Telles do Carmo (Universidade Federal Rural do Semi-Árido)
brenobarros@ufersa.edu.br

Fábio Francisco da Costa Fontes (Universidade Federal Rural do Semi-Árido)
fabio_fontes@ufersa.edu.br

Sebastião Mateus Marques de Menezes (Universidade Federal Rural do Semi-Árido)
mateusmarques200@gmail.com

Davi Benevides Pinto (Universidade Federal do Ceará)
davibene@gmail.com

The shortage of blood components is a problem on a global scale. Allied to this issue, there is no substance that can, in its totality, substitute the blood tissue. Because of its perishable characteristic and, considering that it comes from voluntary donation in most of the countries, bringing a big load of uncertainty, this supply chain is complex to be managed. The lack of blood products represents a risk to the health and life of the population, due to its potential to increase the mortality rate and the aging of the population worldwide. In this context, it is necessary to develop strategies to increase the supply and reduce the waste of this material. This research proposes a negotiation protocol based on linear programming in order to support blood components’ exchange among blood banks. The solution was developed based on the transportation problem model, considering the amount of blood components offered or demanded and their respective expiry date and stock levels, represented by a criticality level. The model was implemented using the CPLEX solver and the computational tests were performed with randomly generated data. The model promotes the reduction of blood products waste, since they can be negotiated with a blood bank that need it, who will not suffer from the lack of the corresponding product. It is also observed that the products offered with short expiration date are prioritized over those with a longer period, an important factor due to the high perishability of the blood product. Moreover, for the demanded products, the model prioritizes those that are more critical, in relation to those that are only for the replacement of the stock bank. The protocol developed is an intelligent negotiation tool able to support the blood bank managers when deciding about blood components exchange, improving the quality of the negotiations among blood banks stocks, reducing the waste and improving the offer of these products.

1. Introduction
Blood donation is still a problem of worldwide interest because there is no substance that can, in its totality, replace the blood tissue. The blood banks face challenges in maintaining the blood supply to meet specific and emergency needs, putting the population's health and life at risk (RODRIGUES; REIBNITZ, 2011). These challenges relate to the nature of the material, the difficulty of maintaining regular donors, as well as its importance for sustaining life. Allied to the importance of this material, blood products are perishable, which complicates things even further. Shortages lead to high costs for society, since they can cause increase mortality rates (BELIËN; FORCÉ, 2012).

Chapman et al. (2004) declare that blood products’ inventory management is complex. To achieve the maximum use of a freely given resource, it is important to understand the complex interrelations of supply and demand and the factors that impact upon them. Thus, an efficient inventory management is crucial, considering it represents a trade-off between shortage and wastage. The challenge is to keep enough stock to ensure a 100% supply of blood while keeping time expiry losses at a minimum (STANGER et al., 2012).

Ouhbi et al. (2015) add that blood donation is seen as a noble act as it helps save precious human lives. Blood transfusion demands increase with catastrophes, wars and diseases. The search for blood donors to meet all this need is a constant work of the health authorities, considering that blood donation is a voluntary act of solidarity in many countries (MORAES; MOREIRA, 2015).

According to the Brazilian National Health Surveillance Agency - ANVISA (2021), an average of 3.6 million blood bags are collected per year. The Brazilian index of donors is approximately 1.7% of the population. According to World Health Organization (WHO) parameters, to maintain regular stocks it is necessary that approximately 3.5% of the population do so regularly.

The emergence of COVID-19 has led to an enormous anxiety among blood donors and therefore, the blood community has been affected adversely. Having disrupted so many processes world-wide, the blood transfusion services are no exception. (RATURI; KUSUM, 2020). Besides that, Pimenta and Souza (2020) affirm that the COVID-19 pandemic has pushed donors too far away and, as a consequence, as informed by Hemorio (the coordinating blood bank of the state of Rio de Janeiro, Brazil), in May of 2020, the stock of safe blood had a decrease of up to 38% in donations, in comparison to the same period of 2019, only in the municipality of Rio de Janeiro.
According to ANVISA (2021), 9,176,050 units of blood components were produced in Brazil in 2019: 37.4% of the production was used in transfusion procedures and 42.6% of the units produced were discarded. Given the scarcity of blood stocks in Brazil and the high volume of discarded blood, it is urgent to develop policies and tools that can reduce waste and increase the level of service to society.

Perera et al., (2009), in its study of 203 hospitals in the United Kingdom, Wales and Northern Ireland, shows statistically that the 93 hospitals that shared their inventory had a higher level of care and a lower waste rate than the 110 hospitals that responded by not sharing their inventory. As such, inventory negotiation protocols can deal with this problem.

In this context, this project develops a negotiation protocol to support blood products exchange among blood banks, in order to increase blood products’ offer, as well as minimize the waste of this material.

2. Literature Review

This topic presents the main methods related to the approach adopted in this research. The developed models are solved using approaches based on mathematical programming, heuristics or simulation.

A study conducted by Stanger et al., (2011) in the United Kingdom (UK) analyzes the impact of hospital size and variability of demand on red cell time expiry wastage in hospitals and identifies the benefits and barriers to effective stock sharing relationships. As results, the authors showed a significant relationship between hospital size and time expiry levels of red cells. Stock sharing requires and creates trust between hospitals, it can be seen as a precursor for further collaboration. In addition, a key factor is the flexibility of stock management to reduce material waste (STANGER et al., 2011).

Another important study to be mentioned is the Blood Stock Management Scheme (BSMS). As stated by Cotton (2019) was launched in 2001 as a partnership between hospitals and blood services to maximize the use of donated blood by increasing the understanding of blood inventory management across the whole supply chain. Central to the work of the BSMS is VANESA, a data management system where hospital and blood service data is collected. Hospitals using VANESA can benchmark their data using categories based on their hospital profile (COTTON, 2019).

In their study, from data collected by BSMS, Perera et al. (2009) analyzes the days worth of stock (Issuable Stock Index - ISI) and wastage in relation to data continuously collected...
The main types of wastage in BSMS hospitals are time expiry, units left out of temperature control and fridge failure. As a result, there was a significantly higher ISI in hospitals that had a stock sharing relationship with another hospital compared with those that did not. WAPI, however, was significantly lower for those hospitals with a stock share relationship.

Yates et al. (2017) exemplify in their work a practice currently undertaken by approximately one-third of hospitals in UK that is lateral transshipments or stock sharing of blood units close to expiry between hospitals, reducing wastage across the supply chain. The main advantages of stock sharing agreements are for the smaller partners, who tend to maintain an extremely high level of stock, with a consequent waste.

Carden and Dellifraine (2005) developed a study on centralized and decentralized blood banks, highlighting the learning that can be had with each form of organizational structure and assessing customer satisfaction. Centralized blood banks operate as a large network. They may be able to compensate for blood shortages in one area by transferring excess blood supplies to shortages areas process known as “resource sharing” (CARDEN; DELLIFRAINE, 2005).

Duan and Liao (2013) in their study consider maximum shortage constraints as well as centralized and decentralized inventories. Computational results show that adopting centralized control over the whole platelet supply chain greatly helps in reducing the system expected outdate rate from 19.6% down to 1.04%, on average, while keeping sufficiently high fill rate at each entity. The message is that hospitals and the blood bank should look for ways to collaborate with each other in a manner as close to a centralized control as possible (DUAN; LIAO, 2013).

Hosseinifard and Abbasi (2016) study the blood supply chain modelled as a two-echelon inventory system where the items arrive at the first echelon (the blood bank) stochastically and stochastic demand is realized at the second echelon (the hospitals). In their proposed structure, some of the hospitals in close proximity of each other maintain centralized inventories to serve their demands in addition to the demands by other neighbor hospitals. The results demonstrate that centralization of hospitals’ inventory is a key factor in the blood supply chain and can increase the sustainability and resilience of the blood supply chain. (HOSSEINIFARD; ABBASI, 2016).

Do Carmo et al., (2020) present a blood inventory management system implemented as a software, DOAR, able to meet demand while minimizing blood bags wastage. The purpose of the software is to provide a link between the demand by blood products and collected blood.
bags. Rytile and Spens (2006) develop an application of discrete event simulation (DES) modeling in the blood transfusion services. The model studied inventories and distribution policies measured through indicators such as outdated, cost and back orders.

Kamp et al. (2010) collect data from several major blood donation services that were used to analyze management of blood supplies in Germany. Routine management of RBCs were extrapolated to epidemic and pandemic situations using computer simulations with a mathematical model that allows for analysis of deficits in blood supplies.

Despite the identification of many studies in the literature that address the difficulty of blood supply chain management and that propose to solve the problem of scarcity or waste of this product type through mathematical models, there are no researches dealing with negotiation or exchange of blood products between blood banks. Thus, this gap was identified to be studied and explored.

For the problem in question, operational research, through the transportation problem modeling, it was considered an approach able to operationalize an intelligent negotiation protocol between blood banks, aiming to reduce waste and to increase the products’ offer to the society.

3. Methodology

This topic presents the methodology followed for the development of a negotiation protocol for sharing stocks among blood banks, able to support decision-making process related to blood products exchange. In order to develop a consistent and structured method that clearly describes the development of the negotiation protocol, the Figure 01 illustrates the steps proposed in the research.

![Figure 01 - Structure of the proposed method](source: Own authorship (2021))
3.1. Modeling the negotiation procedure

The objective of the first step is understanding the negotiation characteristics in a broader way and raise as many requirements as possible for the structuring of the negotiation protocol. These requirements can be identified in the literature and through interviews with blood bank managers.

To start this identification, two local visits were made to the Mossoró blood bank, in Rio Grande do Norte state, to understand how they manage their stocks, the flow of information about the demand for blood products, who are the blood partners and how the exchange of materials occurs today. Based on a previously defined questionnaire, interviews were conducted with the blood bank professionals of Mossoró, Currais Novos, and Pau dos Ferros.

Through an initial interview with their managers, the difficulties encountered in managing the stocks of blood products were reported. In addition to not yet receiving a number of donations large enough to meet the demands, the high rate of material disposal due to its perishability is also a worrying factor.

In order to standardize this process of exchanging blood products, the entire current process was mapped in Business Process Management Notation (BPMN) with aim at understanding in detail the actions, activities and documents that permeate this process.

3.2. Development of the mathematical approach

After the identification of requirements, we developed the mathematical model. For this, two approaches of the transportation problem were adopted: the first was based on the classic approach of the model and the second is a variation that associates penalties to supply and demand, considering the expiry date of the blood product and the stock's critical level, respectively.

Some assumptions were determined to model the problem:

a) The problem addresses the main blood products found in the stocks of blood banks;

b) If in a supply there are blood products of the same type, but with different expiration time, it will be considered the most critical value;

c) Resources such as transportation and professionals involved are sufficient to meet all the demand.

Then, for the first approach, variables and parameters are presented in Table 01.
Table 01 - Description of the model for approach 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin blood bank</td>
<td>$i = 1, 2, ..., n$</td>
</tr>
<tr>
<td>Destination blood bank</td>
<td>$j = 1, 2, ..., n$</td>
</tr>
<tr>
<td>Type of shared blood product</td>
<td>$k = 1, 2, ..., m$</td>
</tr>
</tbody>
</table>

Sets

<table>
<thead>
<tr>
<th>Description</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply of blood bank i of blood product k</td>
<td>$O_{ik}$</td>
</tr>
<tr>
<td>Demand of blood bank j of blood product k</td>
<td>$D_{jk}$</td>
</tr>
</tbody>
</table>

Decision variable

<table>
<thead>
<tr>
<th>Description</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of type k blood product from the blood bank of origin $i$ to the destination blood bank $j$</td>
<td>$X_{ijk}$</td>
</tr>
</tbody>
</table>

Source: Own authorship (2021)

Table 01 shows a variable $X_{ijk}$, which illustrates the amount of blood product $k$ to be transported between the supplying blood bank $i$ and the destination blood bank $j$. Each supplier has a defined $O_{ik}$ supply offer capacity and each receiving blood bank has a demand capacity, expressed by $D_{jk}$.

The corresponding objective function used in the first approach, expressed in equation (1), aims to minimize discard as it attempts to optimize the exchange system.

Objective function (approach 1):

Minimize:

$$\sum_{i=1, i \neq j}^{n} \sum_{k=1}^{m} \left( O_{ik} - \sum_{j=1, i \neq j}^{n} X_{ijk} \right) + \sum_{j=1, i \neq j}^{n} \sum_{k=1}^{m} \left( D_{jk} - \sum_{i=1, i \neq j}^{n} X_{ijk} \right)$$  \hspace{1cm} (1)

Subject to:

The total number of units transported, from origin $i$, must be less than or equal to the $O_i$ supply offer of origin:

$$\sum_{j=1, i \neq j}^{n} X_{ijk} \leq O_{ik}, \forall i = 1, \ldots, n \forall k = 1, \ldots, m$$  \hspace{1cm} (2)

The number of units transported to destination $j$, must be less than or equal to their absorption capacity $D_j$:  

6
\[
\sum_{i=1, i \neq j}^{n} X_{ijk} \leq D_{jk}, \forall j = 1, \ldots, n \text{ e } \forall k = 1, \ldots, m \tag{3}
\]

Non-negativity:
\[
X_{ijk} \geq 0, \forall i = 1, \ldots, n, j = 1, \ldots, n \text{ e } k = 1, \ldots, m \tag{4}
\]

The second approach can be described as an adaptation of the classic transportation problem with the addition of criticality indexes in supply and demand. For the offer, this index refers to the expiration date of the blood products, since this vary according to the type of blood product and if they are not used within the deadline they can be discarded. For the demand, this index is related to the criticality of the need for these blood products, which can be used to: replace the stock of the bank, for a scheduled elective surgery, or for an emergency transfusion. The corresponding variables used in the second approach are expressed in Table 02.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin blood bank</td>
<td>i = 1, 2, ..., n</td>
</tr>
<tr>
<td>Destination blood bank</td>
<td>j = 1, 2, ..., n</td>
</tr>
<tr>
<td>Type of shared blood product</td>
<td>k = 1, 2, ..., m</td>
</tr>
<tr>
<td>Supply penalty level</td>
<td>p = 1, 2, ..., p0</td>
</tr>
<tr>
<td>Demand penalty level</td>
<td>q = 1, 2, ..., pd</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sets</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penalty vector associated with the offer of each blood product k (related to expiration date) from blood bank i</td>
<td>PO_{ik}</td>
</tr>
<tr>
<td>Penalty vector associated to the demand of each blood product k (related to stock level criticality) from blood bank j</td>
<td>PD_{jk}</td>
</tr>
<tr>
<td>Supply of blood bank i of blood product k</td>
<td>O_{ik}</td>
</tr>
<tr>
<td>Demand of blood bank j of blood product k</td>
<td>D_{jk}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decision variable</th>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of type k blood product from the blood bank of origin i to the destination blood bank j</td>
<td>X_{ijk}</td>
</tr>
</tbody>
</table>

Source: Own authorship (2021)
Table 02 shows the elements $p$, which is the penalty associated with the supply and $q$, which is the penalty associated with the demand. Thus, the first part of the objective function is multiplied by a parameter, $PO_{ik}$, which represents the penalty associated with the expiration date of each blood product, favoring the distribution of components with shorter shelf life. The second part of the objective function is multiplied by a parameter, $PD_{jk}$, which refers to the penalty associated with the criticality of the need for that type of component, favoring the supply of blood banks with reduced stocks.

Then, for the second approach, the objective function is expressed by the equation (5) and it aims to minimize the offered quantity that is not distributed as well as the demanded quantity which did not meet the requested amount.

Objective function (approach 2):

Minimize:

$$\sum_{i=1, i\neq i}^{n} \sum_{j=1, j\neq j}^{m} \left( O_{ik} - \sum_{j=1, j\neq j}^{n} X_{ijk} + d_{ij} \right) \cdot PO_{ik} + \sum_{j=1, j\neq j}^{n} \sum_{k=1, k\neq k}^{m} \left( D_{jk} - \sum_{i=1, i\neq i}^{n} X_{ijk} \right) \cdot PD_{jk} \quad (5)$$

Subject to:

The total number of units transported, from origin $i$, must be less than or equal to the $O_i$ supply capacity of origin:

$$\sum_{j=1, j\neq j}^{n} X_{ijk} \leq O_{ik}, \forall i = 1, \ldots, n \text{ and } k = 1, \ldots, m \quad (6)$$

The number of units transported to destination $j$, must be less than or equal to their absorption capacity $D_j$:

$$\sum_{i=1, i\neq i}^{n} X_{ijk} \leq D_{jk}, \forall j = 1, \ldots, n \text{ and } k = 1, \ldots, m \quad (7)$$

Non-negativity:

$$X_{ijk} \geq 0, \forall i = 1, \ldots, n, j = 1, \ldots, n \text{ and } k = 1, \ldots, m \quad (8)$$

For data collection, it is essential to agree on the reference scale associated with the $PO$ and $PD$ parameters, so that the blood bank managers can unify the language when requesting or offering the blood products. Thus, two parameters were used, which must be established together with the blood banks participating of the network. The first parameter is the expiration date for the offer and the second is the criticality of the need for the demand. Table 03 shows a reference
scale divided into three different levels. The goal of the multiplication factor is to prioritize everything that is very critical, then what is not very critical, and finally what is not critical.

<table>
<thead>
<tr>
<th>Reference scale</th>
<th>Numerical scale</th>
<th>Multiplication factor</th>
<th>Offer (expiration date)</th>
<th>Demand (criticality of need)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1</td>
<td>1</td>
<td>Expiration date in more than one week</td>
<td>Only to replenish the stocks</td>
</tr>
<tr>
<td>Medium</td>
<td>2</td>
<td>10</td>
<td>Expiration date between the third and the seventh day</td>
<td>Low criticality</td>
</tr>
<tr>
<td>High</td>
<td>3</td>
<td>100</td>
<td>Expiration date in less than three days</td>
<td>High criticality</td>
</tr>
</tbody>
</table>

Therefore, the mathematical model was developed, with the objective functions and constraints for the first and second approach. The variables were identified and described according to the model. From this information, codes were implemented in C++ programming language, to be solved later in CPLEX version 12.10.0.

3.3. Validation of the negotiation protocol
This validation was performed through random generated instances respecting the constraints established in the transportation problem. Thus, the blood bank of origin cannot be the same as the destination blood bank for the same type of product and the values offered and demanded must be greater or equal to zero. For this approach all the 15 blood banks in the state of Rio Grande do Norte will be considered.

The fictitious instances randomly generated in Excel were designed to test the mathematical modeling, so entire non-negative values were assigned for each blood product and each blood type. Data were randomly assigned values between 0 and 20 using Excel. Then, for the offer penalty, random values from 1 to 3 were assigned to the offered blood products that varied their quantity from 1 to 20 and 0 to those that had the value of 0 in the quantity offered. In the same way, it occurred to form the demand matrix, however if the blood product had already been offered by the blood bank, there is no need to demand it too. Then, the values from 1 to 3 were transformed according to the multiplication scale associated with the penalties, in 1, 10 and 100, respectively.
Figure 02 illustrates how the mathematical model works and its importance to enable negotiations and decision-making in an optimal way. The mathematical model provides the best combination so that the negotiations and exchanges of blood products among blood banks are carried out and the blood product demands are met, increasing the level of service to the population and reducing the materials to be discarded.

4. Results

To test the model, the red blood cell concentrate component and its variations of type and blood factor were used, resulting in eight products. For approach 1, random instances for offer and demand were computationally generated, and for approach 2, in addition to these, instances were also generated for the penalties associated with offer and demand. Table 04 shows the result generated by the model implemented using CPLEX. Out of the eight products offered, six were distributed and 13 variables assumed value 1.
Table 04 - Optimal solutions for red blood cell concentrate sharing in approach 1

<table>
<thead>
<tr>
<th>Origin</th>
<th>Offer</th>
<th>Demand</th>
<th>Product</th>
<th>Shared quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>Hemocenter Regional de Caxias</td>
<td>11</td>
<td>RBCA</td>
<td>11</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>6 TA Hospital 1º Pedra Bezerro - Natal</td>
<td>3</td>
<td>RBCD</td>
<td>3</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>17 TA Hospital Mat Alcile Fernandes - Natal</td>
<td>14</td>
<td>RBCD</td>
<td>14</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>17 TA Hospital Mat Alcile Fernandes - Natal</td>
<td>16</td>
<td>RBCD</td>
<td>16</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>14 TA Hospital Regional Lindolfo Gomes Vidal - Santo Antônio</td>
<td>16</td>
<td>RBCD</td>
<td>16</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>14 TA Hospital Regional Lindolfo Gomes Vidal - Natal</td>
<td>14</td>
<td>RBCD</td>
<td>14</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>14 TA Hospital Regional Lindolfo Gomes Vidal - Natal</td>
<td>14</td>
<td>RBCD</td>
<td>14</td>
</tr>
<tr>
<td>Collection and Transfusion Units - Pau dos Ferros</td>
<td>Collection and Transfusion Units - Currais Novos</td>
<td>6</td>
<td>RBCD</td>
<td>6</td>
</tr>
</tbody>
</table>

Source: Own authorship (2021)

For approach 2, as shown in Table 05, six of the eight available products were distributed and 16 variables assumed value 1.

Table 05 - Optimal solutions for red blood cell concentrate sharing in approach 2

<table>
<thead>
<tr>
<th>Origin</th>
<th>Offer</th>
<th>Demand</th>
<th>Product</th>
<th>Shared quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>Hemocenter Regional de Caxias</td>
<td>11</td>
<td>RBCA</td>
<td>11</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>6 TA Hospital 1º Pedra Bezerro - Natal</td>
<td>3</td>
<td>RBCD</td>
<td>3</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>17 TA Hospital Mat Alcile Fernandes - Natal</td>
<td>14</td>
<td>RBCD</td>
<td>14</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>17 TA Hospital Mat Alcile Fernandes - Natal</td>
<td>16</td>
<td>RBCD</td>
<td>16</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>14 TA Hospital Regional Lindolfo Gomes Vidal - Santo Antônio</td>
<td>16</td>
<td>RBCD</td>
<td>16</td>
</tr>
<tr>
<td>Hemocenter Regional de Mossoró</td>
<td>14 TA Hospital Regional Lindolfo Gomes Vidal - Natal</td>
<td>14</td>
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<td>RBCD</td>
<td>14</td>
</tr>
<tr>
<td>Collection and Transfusion Units - Pau dos Ferros</td>
<td>Collection and Transfusion Units - Currais Novos</td>
<td>6</td>
<td>RBCD</td>
<td>6</td>
</tr>
</tbody>
</table>

Source: Own authorship (2021)

Considering the use of criticality indexes associated with offer and demand, there is an optimization from approach 1 to approach 2. The protocol that we use to operationalize this intelligent negotiation is able to prioritize the offers and demands that are more critical according to their expiration date and usage needs, respectively. Analyzing Figure 03, it can be observed that comparing approach 1 and 2, there were many differences in the blood products that were shared. Thus, with criticality index 1 (low), 26 blood
products were distributed in approach 1 and zero in approach 2. For criticality index 2 (medium), 49 blood products were shared in approach 1 and 17 in approach 2. And for criticality index 3 (high), which represents products with expiration dates in less than three days, 20 blood products were shared in approach 1 and 78 in approach 2.

Figure 03 - Comparison between approach 1 and 2, considering the quantity of products offered close to the expiration date that were negotiated

![Bar chart showing the difference between approach 1 and 2 for high, medium, and low criticality products.](source)

Figure 03 shows the difference between each approach, according to each criticality index. Thus, it can be concluded that the protocol developed in approach 2 distributed approximately 400% more high criticality products compared to approach 1, representing 58 bags of blood products that were critical but were not distributed by approach 1.

In the model studied, the offer is greater than the demand, so the two models will meet the demand, presenting no difference only in the aggregate result, as shown in Figure 03 for offer. However, for approach 1 and 2 the origin and destination blood banks are different from each other, so the models present different results for demand as well.

5. Conclusions

The present study fills a scientific gap, because there are no researches dealing with negotiation or exchange of blood products between blood banks. The model is able to reduce the level of discarding by prioritizing the blood products with earlier expiration data. The study validates
the importance of working with the criticality index, since this index greatly improves the negotiation performance, with potential to reduce the discard.

Given the current situation that we live in globally, especially in Brazil with the worsening of the Covid-19 pandemic, the relevance of this study is to help reduce the disposal and improve the offer of these products to the population.

It is worth mentioning that this analysis was performed only for one blood product, the red blood cell concentrate. Expanding this methodology to the others blood components, we have a large quantity of products that will not be wasted and can be useful in other blood banks.

As a recommendation for future studies, it is important to take into consideration the distance between the blood banks. Thus, the association of distances becomes a decision support factor in the case of multiple solutions, prioritizing blood banks that are part of the same region.

6. Acknowledgments

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