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| RESEARCH ARTICLE

Blood Supply Chain Management: A Review of Different Solution Techniques

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| ABSTRACT
Managing the blood supply network is crucially important. The lack of blood might result in patient problems and even death. Blood loss, on the other hand, results in hefty expenses. To reduce the levels of shortage and wastage, the blood product supply chain must make the best decisions possible. Numerous writers have researched this field because of the intricacy and significance of the blood supply chain. This essay aims to provide an overview of research on the blood supply chain. Studies that were published from 2015 to 2022 were therefore examined and categorized. This survey's main contribution is to update the body of research on the blood supply chain with a new classification and critically evaluate the state of the art in this field. Environments for making decisions, problems with the blood supply chain's design, working methods, decision-making, modeling, problem-solving methods, and data features are among the suggested categories. In addition, the shortcomings and inadequacies in the existing literature are emphasized, and potential study approaches are presented.

| KEYWORDS

Blood supply chain, Inventory management, Health care, Perishable products.

| ARTICLE INFORMATION

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1. Introduction

Blood transports nutrients and oxygen to the tissues and lungs, among other functions (American Society of Hematology, 2022). It becomes a perishable substance when removed from the human body and is used in surgical procedures, organ transplants, and treatments for cancer and blood problems.

The blood supply chain (BSC), which regulates the flow of blood products from donors to patients, is made up of five echelons: donors, mobile blood collection sites (CSs), blood centers (BCs), demand nodes, and patients. In addition, demand nodes can be found in clinics, hospitals, and other transfusion venues. Mobile CSs, BCs, and demand nodes must coordinate the six essential steps in blood donation: collection, testing, component processing, storage, distribution, and transfusion.

The majority of blood is composed of red blood cells (RBCs), platelets (PLTs), plasma, and cryoprecipitate antihemophilic factor (cryo) (American Red Cross, 2022). Through apheresis, an automated procedure that separates the needed characteristics from the blood, these components can be obtained. The remaining components can either be mechanically removed from a unit of whole blood (WB), termed as WB-derived (Beliën & Forcé, 2012), or they can flow back into the donor at the same time.

However, the normal source of blood is voluntary contributions, which have some serious drawbacks, such as a dearth of donors, a delay in testing, and a brief lifespan (Jansman & Hosta-Rigau, 2018). Therefore, the development of artificial oxygen carriers that serve as "blood substitutes" is of interest. The therapeutic uses of these alternatives are primarily being researched in trauma and major surgery (Spahn, 2018). However, many products have issues with safety and effectiveness that need to be resolved by additional research despite their tempting attributes (Alayash, 2017).

It is not ideal to waste these resources, and it would be better if there were more blood products available and their running expenses were lower. However, Lprimarily Likewise, scarcity is undesirable as it may result in procedures being postponed, patients going untreated, and fatalities (World Health Organization, 2022). Therefore, it is crucial to streamline the BSC's operational procedures.

Reviewing and assessing recent studies that have been conducted on the BSC is the main objective of this essay. The authors of earlier surveys were Belin and Forcé (2012) and Osorio et al. (2015). For example, Beliën and Forcé (2012) found that, between 1976 and 2010, the years from 2005 to 2010 had the most BSC publications. For this reason, this work considers international journal publications since 2005. A final collection of 36 articles was obtained through the search method. The following are the main contributions of this paper and how it differs from studies by Belin and Forcé (2012) and Osorio et al. (2015):

- The BSC literature review has been updated. Because the previous studies only considered articles published up until 2014 (Belin & Forcé, 2012; Osorio et al., 2015).
- A new taxonomy with more precise data is presented. The elements of our analysis are as follows: different decision-making environments, different BSC problems in the literature, additional modeling and solution approach for each domain, and numerous criteria for judging and optimizing BSC decisions.

Problems found using this taxonomy to guide future investigations. Therefore, the remainder of the text is organized as follows. We outline the technique for choosing papers in Section 2. Section 3 describes the BSC-related surveys. According to the proposed taxonomy, the classification of items is shown in Section 4. In Section 5, there is a review of the critical discoveries in the literature and the future directions for research. Finally, the conclusions are presented in Section 6 at the end.

2. Review methodology and scope

This essay reviews published works that examine the BSC:

- The scope of the study is limited to scientific research published between 2015 and 2022,
- The application of numerical techniques and models. Not included are studies on clinical and medical topics, the collection and processing of blood samples, epidemics, natural disasters, or the logistics of providing humanitarian relief.

A total of 36 items were produced due to the search technique. Fig. 1 displays the distribution of papers according to publication date. There is a rising tendency in the number of publications. With 12 articles, the year 2019 has the most publications overall. The periodicals with more than two contributions to the BSC studies are shown in Table 1. The first place with 22 articles is Elsevier. They are taken from the last round of papers.

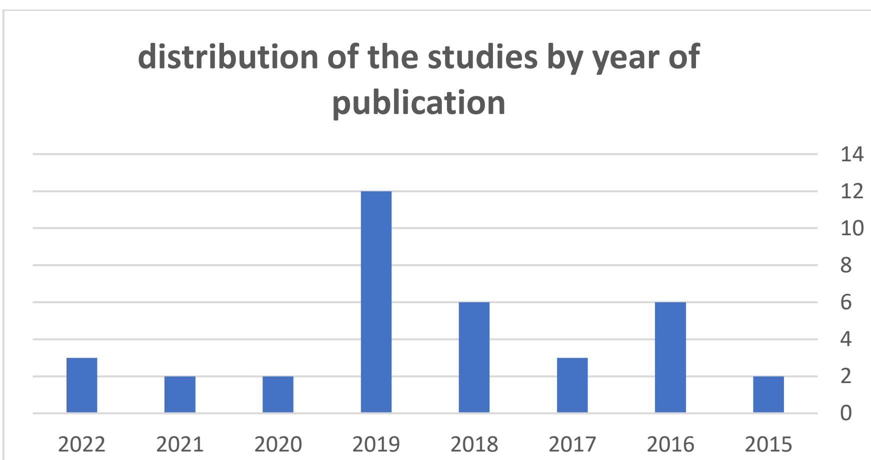


Fig. 1. Distribution of the studies by year of publication.

Table 1 The most influential international magazines.

Journal	No. of papers
Elsevier	22
IEEE	4
springer	3
Energies	1
Wiley	1
Avxiv	1
research.skylineuniversity	1
research square	1
Mdpi	1
ResearchGate	1

3. Previous evaluations of the BSC

If not earlier, the BSC study began in 1966 (Belin & Forcé, 2012). Since then, many publications have allowed authors to publish surveys. For example, An overview of inventory management in the BSC may be found in the publications by Stanger et al. (2012) and Lowalekar and Ravichandran (2013).

Based on the available literature and historical data from the United Kingdom, Stanger et al. (2012) identified the best practices for hospital PLT inventory management. In 2013, Lowalekar and Ravichandran identified information gaps when examining the features of blood banks in India.

Belin and Forcé created a review of the available literature on BSC management (2012). These authors categorized 98 publications using the following eight criteria: case studies, stochastic and de- terministic methodologies, solution methods, performance metrics, explored problems, modeling methods, echelons, and network topology.

Osorio et al. conducted the most recent survey (2015). This study examined the papers in light of operating procedures and their constraints. Consequently, the reviews listed above and this article differ significantly.

The review by Stanger et al. (2012) was released in 2012, and publications from 1966 to 2010 and 2014, respectively, were included in the surveys by Belin and Forcé (2012) and Osorio et al. (2015). In addition to a critical assessment of the state of the art in this field, the literature review has to be updated. The taxonomy proposed in this article allows for a more detailed classification of the existing material. The several decision-making settings in the BSC's architecture and the modeling and solution approaches for each environment are among the topics covered in this document's study.

4. Taxonomy

A taxonomy approach for classifying and incorporating the BSC literature is presented in this section. The following categories and subcategories address the key elements mentioned in the reference papers: environments for forecasting and decision-making, network structure, blood products, operational procedures, nature of the problem/decision-making process, modeling methods, and data characteristics.

4.1. Environments for forecasting and making decisions

Decision-making and predicting general contexts are the subject of this literature study. The contexts for making decisions are both deterministic and uncertain. In a deterministic scenario, the decision-maker is aware of the details of the problem parameters beforehand. Due to the numerous potential outcomes that may need to be discovered and analyzed, this setting is very complicated (Rosenhead et al., 1972). However, the BSC contains intrinsic uncertainties for several elements, including supply and demand.

4.2 .Problems with the BSC's design

4.2.1 Topology of the network and echelons

Donors, mobile CSs, BCs, demand nodes, and patients make up the five strata in which the operational activities for the BSC are carried out. The five categories of BCs—fixed CSs, labs, processing centers, storage facilities, and distribution centers—can be grouped in one location or separated geographically. A fixed CS and a mobile CS differ from one another. The former has a set location, but the latter requires a location choice for each time of the planning horizon. This suggests that moving CSs will cost more to transport. However, the mobile CS enables more excellent blood collection because it is situated in workplaces, public spaces, or universities. The stationary CS often has a larger capacity and is set up for the apheresis-based collection of WB and products. Although there are mobile CSs with resources for apheresis collection, the primary purpose of these vehicles is to collect WB. The literature contains synonyms for the terminology used to describe the echelons in this paper, which are included in Table 2.

Term	Synonyms in previous studies
Fixed CS BC	The temporary facility Collection Blood facilities Donation point site CS facility Blood facilities National blood service Blood bank
Mobile CS	Blood camp Blood donation centers Donation campaigns Bloodmobile
Demand node	Donation clinic Supply point Demand zone/point Transfusion point Hospital

4.2.2 Blood components

The BSC's mission is to ensure that blood products are accessible when patients need them. To address their disease, they can get WB or specialized blood components. The primary functions, shelf life, and storage requirements of the main blood components are shown in Table 3. Country requirements to identify and prevent bacterial contamination define the PLT shelf life. For instance, the PLT shelf life is just five days in the United States, three days in Japan, and up to 7 days in most nations in the European Union and elsewhere (2022). PLT (3–7 days) and WB are the blood products with the shortest shelf life (35 days).

Table 3 Blood components Shelf life. American Red Cross (2022).

Blood components	Shelf life	Storage conditions
WB	21\35 days	18-24 °C
RBC	42 days	2-10 °C
PLT	3-7 days	20-24 °C
Plasma	1 year	≤ -30 °C
Cryo	1 year	≤ -30 °C

These Five blood components —WB, PLT, RBC, plasma, PLT by apheresis, plasma by apheresis, and cryo—are distinguished in this section. The references are included in Table 4 by the considered blood components. Some articles were solely about "blood," and they were labeled as "unclear."

Table 4: Reference works that take into consideration the blood components.

Blood components	No of studies	Reference
WB	6	John Blake, et al, 2016*Sima M, et al, 2016 D.M.S. Kumari, et al, 2016*Mary Dillon, et al, 2017 Pritha Dutta, et al, 2019*Henrique L.F. , et al, 2019
RBC	11	Sima M, et al, 2016*Mary Dillon, et al, 2017 Shiva Moslemi et al., 2017*Marzieh Eskandari-Khanghahi et al., 2018*Sima M et al., 2018*Maryam Dehghani et al., 2019 Mohsen Naghipour , et al, 2019*A. Pirabán , et al, 2019 Suchithra Rajendran, et al, 2019*Mohammad Arani , et al, 2019 Nazanin Haghjoo, et al, 2020
PLT	3	Sima M, et al, 2016*Mary Dillon, et al, 2017

		Seyyed-Mahdi , et al, 2019
Plasma	4	John Blake, et al, 2016*Sima M, et al, 2016 A. Ahmadi, et al, 2016*Mary Dillon, et al, 2017
Unclear	19	Samer Hamadneh,et al,2021*Mohammad Shokouhifar,et al,2021 NasurudeenAhamedN, et al, 2022*Ali Sibevei,, et al, 2022 Ana Torrado, et al, 2022*Kate Smith-Miles, et al, 2020 Neil K. , et al, 2019*Jihed Jemai , et al, 2019 Absalom E. Ezugwu , et al, 2019*Sepideh Ghasemi,2019 Bayan Hamdan, et al, 2018*Mohammad Reza, et al, 2018 Hamilton C. Tsang, et al, 2018*Ali Ekici, et al, 2018 Amir H, et al, 2017*Kartikeya Puranam, et al, 2016 Serkan Gunpinar, et al, 2016*Ismail Civelek, et al, 2015 Ke-Ming Wang, et al, 2015

4.2.3. Demand and Donation

Donation demand and volume are essential for simulating the BSC. These parameters were established in the settings of forecasting and making decisions by the reference studies. Table 5 lists the articles that considered the two characteristics and those that focused solely on supply. Some articles were categorized as "unclear" because the writers failed to specify the decision environment group sufficiently.

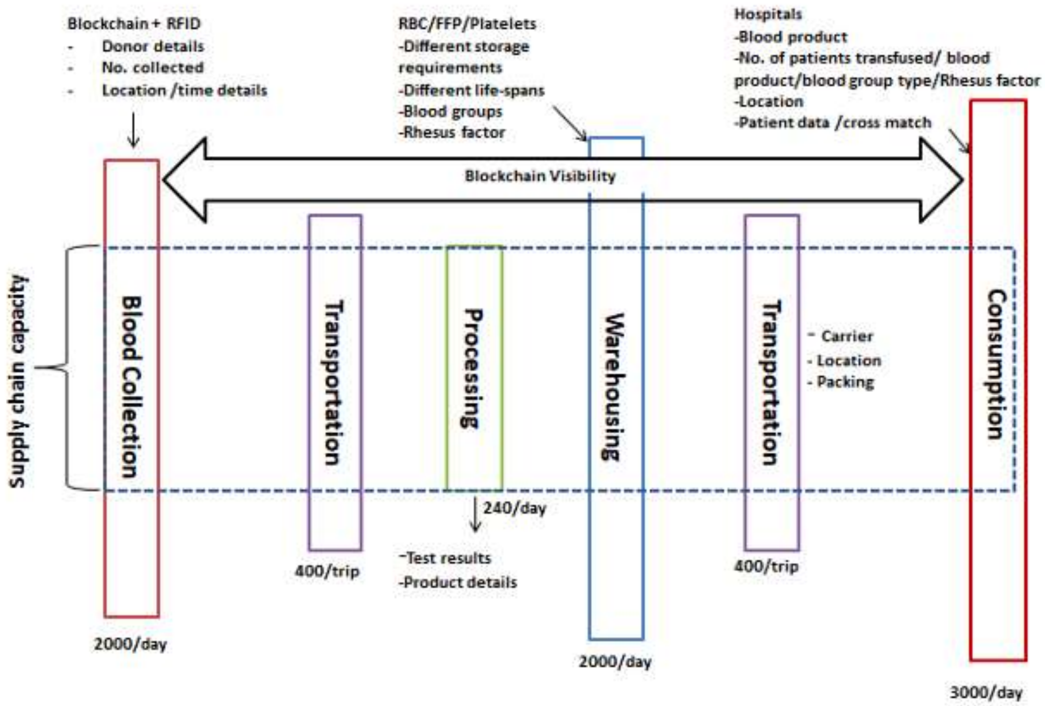
Table 5 lists the articles that took into account the Demand and Donation and those that focused solely on supply.

Blood components	No of studies	Reference
Demand and Donation	15	Ismail Civelek, et al, 2015* Ke-Ming Wang, et al, 2015 Serkan Gunpinar, et al, 2016*Mary Dillon, et al, 2017 Ali Ekici, et al, 2018*Marzieh Eskandari-Khanghahi, et al, 2018 Mohammad Reza, et al, 2018*Hamilton C. Tsang, et al, 2018 Absalom E. Ezugwu , et al, 2019*Jihed Jemai , et al, 2019 Mohsen Naghipour , et al, 2019*Neil K. , et al, 2019 Henrique L.F. , et al, 2019*Kate Smith-Miles, et al, 2020 Ali Sibevei,, et al, 2022
supply	17	John Blake et al., 2016*D.M.S. Kumari et al., 2016 A. Ahmadi, et al, 2016*Kartikeya Puranam, et al, 2016 Amir H, et al, 2017*Sima M, et al, 2018 Bayan Hamdan, et al, 2018*Maryam Dehghani, et al, 2019 Pritha Dutta, et al, 2019*Seyyed-Mahdi , et al, 2019 A. Pirabán , et al, 2019*Suchithra Rajendran, et al, 2019 Mohammad Arani , et al, 2019*Samer Hamadneh,et al,2021 Mohammad Shokouhifar,et al,2021*NasurudeenAhamedN, et al, 2022*Ana Torrado, et al, 2022
Unclear	4	Sima M, et al, 2016*Shiva Moslemi, et al, 2017 Sepideh Ghasemi,2019*Nazanin Haghjoo et al., 2020

4.3 BSC processes and the kinds of problems and decisions made during the planning

The six primary BSC processes—collection, transportation, testing, component processing, inventory management, and transfusion—are used to categorize the principal issues raised by the reference papers. An expanded version of these procedures is shown in Fig. 2.

Fig. 2. The six primary BSC processes (IBM Supply Chain Community)



4.3.1. Blood Collection

The goal of the collection stage is to collect enough blood products to meet demand. Several variables influence blood product availability, including the number of benevolent donors in a region and donation drives. As a result, the blood supply is erratic. Additionally, blood donors must fulfill several standards in order to be eligible. For example, they must weigh at least 50 kg and be 18 years old to enter the European Union (Mohammad Shokouhifar et al.,2021).

WB donation (in single, double, triple, or quadruple bags) and RBC, plasma, or PLT collection by apheresis are the two available collection techniques (Mary Dillon et al., 2017). The primary differences between these collection techniques are the efficiency and blood products obtained. Blood must be stored while WB is collected in individual bags for WB collection. Double, triple, or quadruple bags manage the blood that needs to be divided into parts. A triple pack produces RBC, PLT/cryo, and plasma, while a double bag only produces RBC and plasma. In quadruple bags, RBC, plasma, and buffy coat are made (PLT and white blood cells).

Compared to WB collection, apheresis produces a significantly higher output of blood products. To create a transfusable unit of PLT, for instance, buffy coats from four or five blood units are combined and then centrifuged (John Blake et al., 2016). At the same time, the PLT's basic apheresis unit may only be divided into three trans-fusible units (Sima M et al., 2016). Additionally, the multicomponent apheresis technique enables the donation of many blood components from a single donor (A. Pirabán et al., 2019)

Additionally, the frequency and expense of these procedures can be contrasted. The frequency may vary between nations. Men can donate WB, for instance, once every 56 days in France, whereas women can donate up to once every four months. However, a donor who performs single-PLT apheresis must wait two days before making another donation. Deferral time is the name for this waiting period. As a result, multicomponent apheresis enables the collection of more blood products from a donor over a year (A. Pirabán et al., 2019). However, apheresis involves more expensive equipment and takes longer to complete a donation.

At a stationary CS (BC) or via a mobile CS, donations are gathered from planned and walk-in donors (Ana Torrado et al., 2022). The length of the appointment according to the collection method and the time slots during the day for each method make up the appointment decisions for scheduled donors, as described by Samer Hamadneh et al. (2021) and A. Pirabán et al. (2019). Single mobiles for WB contributions solely or double mobiles for WB plus apheresis donations are both acceptable forms of mobile CS (Samer Hamadneh et al.,2021).

A mobile CS's visit duration has been managed in various methods, most frequently with a minimal gap between two consecutive visits. For example, Bayan Hamdan et al. (2019) assumed that a mobile unit could visit many places concurrently. Other authors described the collection in a particular location as a full-day activity (e.g., Ana Torrado et al., 2022). Furthermore, if the predicted blood potential is noticeably high, A. Ahmadi et al. (2016) permitted visits lasting up to 3 days in the exact location.

The collecting process can be broken down into four steps and requires resources and employees (secretaries, doctors, and nurses) (Ana Torrado et al., 2022). Phase 1 entails welcoming and registering prospective contributors. Clinical tests are performed in Phase 2 to determine whether the donation can be undertaken or if it should be postponed. Phase 3 corresponds to the actual donation, while Phase 4 involves the patient eating a small meal and receiving post-donation care.

To prevent waste from excessive collection, the amount of blood collected in the CS may be stopped at a predetermined point (Ali Sibevei et al., 2022). Three collection policies are taken into account in the literature:

- Collecting the entire quantity from donors (e.g., Ali Sibevei et al., 2022; Serkan Gunpinar et al., 2016);
- Collecting a specific quantity (Q); and
- Collecting the difference between a target inventory level S and the stock level prior to the collection (e.g., Mohammad Reza et al., 2018). Additionally, a discard rate can decrease the amount of blood collected (Henrique L.F. et al., 2019).

The primary components of the collection cost are the blood collection bag, employees, machine use, and operational costs related to the above collection phases.

4.3.2 Transportation

Vehicle fleets are utilized to carry blood from BCs to demand nodes and to transport blood products from CSs to BCs. Regular transfer from CSs to BCs calls for mobile CSs to return to the BCs at the end of each day with the blood they have collected. In addition to the mobile CSs, some writers suggested including shuttles (see Ke-Ming Wang et al., 2015; Serkan Gunpinar et al., 2016; Mary Dillon et al., 2017; and Ali Ekici et al., 2018). A mobile CS only makes its way back to the BC with shuttles after the planning horizon or when it has no collection activities planned anywhere. Shuttles also provides the materials required for collection activities in the subsequent periods to mobile CSs.

Shuttles are also assigned to pick up and deliver the collected WB from mobile CSs to BCs at regular intervals because the WB must be processed within 8 hours of the time of donation to obtain PLT concentrates and cryo (e.g., Sima M et al., 2016; Mary Dillon et al., 2017; Seyyed-Mahdi et al., 2019)

The fleet of vehicles can be homogeneous-capacitated, homogeneous-incapacitated, or heterogeneously-capacitated, according to studies by Serkan Gunpinar et al. (2016) and Mary Dillon et al. (2017). (e.g., Ke-Ming Wang, et al., 2015; Ali Ekici et al., 2018). The fact that the size of the bags used to transport blood products is modest compared to the size of the vehicles was used by Sima M et al. (2016) to justify the use of the uncapacitated fleet.

A vehicle can pick up unused blood products and new blood from mobile CSs on the way back to the BCs after distributing blood from BCs to demand nodes (Ganesh et al., 2014). Some authors (e.g., Mobasher et al., 2015; Rabbani et al., 2017) also took into account the loading/unloading time and the fleet's carbon emissions (see Ana Torrado et al., 2022).

Additionally, decisions on where and how to get there are related. For example, the coverage radius, positioning costs, and facility capacity are the primary considerations in the current literature when determining where to place mobile CSs or BCs (e.g., Jihad Jemai et al., 2019 & Mohsen Naghipour et al., 2019 & Neil K. et al., 2019 & Henrique L.F., et al., 2019 & Kate Smith-Miles, et al., 2020 & Ali Sibevei, et al., 2022). Most distribution costs pay drivers' wages, fuel and maintenance fees, and vehicle amortization costs (Ana Torrado et al., 2022).

4.3.3 .Testing

The BC laboratory receives the blood products once they have been collected. To ensure the security of blood, testing is a challenging process. First, each product's blood type (O+, O, A+, A, B+, B, AB+, and AB) is identified. The effects are then examined for the presence of any diseases. For each type of infection, there are various screening tests available. The decision maker must choose a set of screening tests to determine whether each collected unit is infected because these tests have the potential for false negatives and positives (Mohammad Arani et al., 2019). They must also consider the infection prevalence rates in the donor population (Marzieh Eskandari-Khanghahi et al., 2018). After testing, some of the blood products collected were found to be infected and discarded (Ana Torrado et al., 2022)

4.3.4 Processing of blood component

The acceptable WB is either mechanically divided into components or stored immediately for transfusion. Different elements can be extracted depending on the collection technique and the processing speed/time (Sima M et al., 2018). Large-scale fresh WB component separation may be advantageous for patients, but there may be better options for the BC (Mary Dillon et al., 2017). The procedure expands the range of available blood products while raising storage, processing, and waste expenses. Sima M et al. (2018) suggested figuring out the ideal quantity of fresh WB to be segregated in light of these factors.

Some authors (e.g., Mary Dillon et al., 2017 & Pritha Dutta et al., 2019 & Henrique L.F. et al., 2019) or two days (e.g., John Blake et al., 2016 & Sima M et al., 2016; & D.M.S. Kumari, et al., 2016) were based on the assumption that testing and processing take place, and that blood units are therefore Furthermore, Ana Torrado et al., (2022) anticipated that there are times when there is no component preparation, such as the Christmas and Easter holidays. Therefore, the human and equipment costs are often combined to estimate the processing cost (Neil K. et al., 2019).

4.3.5 Inventory management

The BSC's inventory management is responsible for ensuring that there are enough blood products available. The fact that some goods, like PLTs, have a limited shelf life has caused this procedure to garner the most attention in the literature (see Fig. 3).

The literature on BSC suggests using traditional inventory policies and their adaptations to establish the processing/order quantity and the periodicity. Periodicals (R, Q), (R, S) are the most popular inventory policies (Ana Torrado et al., 2022). (R,s, S). Review periodicity, fixed-order quantity, target level, and reorder point (or safety stock) are represented in these systems by the letters R, Q, S, and s (Neil K. et al., 2019). One day is the most common frequency in the BSC for checking inventory levels (Ana Torrado et al., 2022).

The OIR policy is another one that's applied to periodical inventories. The processing/order quantity in this policy is first established by the (R, S) order-up-to-level policy, which solely considers the number of items in stock. Then, the ratio of "old" items to the total goods is computed. In order to account for potential waste brought on by those "old" items, an additional replenishment is triggered if this proportion rises above a predetermined threshold level. Finally, the amount of additional replenishment is calculated as the sum of all "old" goods (D.M.S. Kumari et al., 2016).

Demand nodes typically review their inventory at the end of the term and send the order to the BC for a regularly scheduled delivery. The orders are shipped overnight, and they are delivered the following day. As a result, using a lead time of zero as a modeling approximation is reasonable (e.g., Neil K. et al., 2019; & Henrique L.F. et al., 2019 & Kate Smith-Miles, et al., 2020 & Ali Sibevei et al., 2022). Moreover, a specified lead time is permitted (e.g., Pritha Dutta et al., 2019; & Seyyed-Mahdi, et al., 2019; & A. Pirabán et al., 2019; & Suchithra Rajendran et al., 2019; & Mohammad Arani et al., 2019 & Samer Hamadneh, et al.,2021; & Mohammad Shokouhifar, et al.,2021; & NasurudeenAhamedN, et al.,2022; & Ana Torrado, et al., 2022).

Demand nodes may request faster orders to refill depleted inventory in addition to the regularly scheduled deliveries and emergency orders to meet demand when there is no product on the shelf (Sima M et al., 2016; & Shiva Moslemi et al., 2017). Regular delivery is preferred to urgent and expedited (Ana Torrado et al., 2022).

The requested blood products are labeled as "unassigned inventory" when they reach the demand node. The required blood products enter a process known as crossmatching, in which the blood compatibility between the donor and the patient is determined once the demand node receives an order. From "unassigned inventory" to "assigned inventory," the crossmatched blood is transferred. Crossmatched blood products that are not used are returned to the unassigned inventory. Crossmatch release period refers to allocating blood to a patient and returning unused units. The crossmatch-to-transfusion ratio (C/T ratio) is the proportion of total crossmatched units to transfused units. The difficulty of inventory management is heightened by the patient's "assigned inventory" and the perishability of blood products.

Additionally, the perishable inventory system issuing policy impacts the degrees of waste and shortage (Amir H et al., 2017). The two most commonly used issuing policies in the BSC are the first-in-first-out (FIFO) policy, which uses the oldest stored product first, and the last-in-first-out (LIFO) policy, which uses the most recently stored product first (e.g., Shiva Moslemi, et al., 2017 & Marzieh Eskandari-Khanghahi, et al., 2018; & Sima M et al., 2018; & Maryam Dehghani, et al., 2019; & Mohsen Naghipour, et al., 2019; & A. Pirabán, et al., 2019). Since doctors prefer to utilize fresher blood, it is only sometimes the case that the oldest units are distributed first (D.M.S. Kumari et al., 2016). Sima M et al. (2016) also provided two scenarios to choose between FIFO and LIFO. Ali Ekici et al. (2018) dissected a modified FIFO strategy. The inventory is divided into two parts for Sima M et al. (2016). Products with an age below the target make up the first stage. Once the first stage is exhausted, the things are provided by the LIFO policy from the second stage. Initially, the products are issued by the FIFO policy. Both FIFO and LIFO strategies can be used to choose blood products using the model used by Ekici et al. (2018).

Some scholars have examined the effects of centralizing inventory. For instance, under Ali Sibevei et al. (2022) arrangement, a hospital keeps a central inventory to meet its demand and that of nearby hospitals. Ali Sibevei,, et al, (2022). They extended the centralization study to include several BSC tiers.

The inventory-related cost metrics are ordering, holding, shortfall, and wastage costs (Neil K. et al., 2019). The holding cost refers to the expenses incurred for the blood products' storage while ensuring all necessary conditions, such as refrigeration (Neil K. et al., 2019). A shortage will emerge if the BC or demand nodes need more stock to match the demand (A. Ahmadi et al., 2016). Shortage expenses may require sporadic production, urgent deliveries, or import/export procedures to get blood products from another BC (Pritha Dutta et al., 2019). The amount of effort put into producing each blood product, including the time spent collecting, transporting, testing, and processing blood, is considered when calculating wastage costs (John Blake et al., 2016).

4.3.6 Transfusion

A patient might have eight blood types: O+, O, A+, A, B+, B, AB+, and AB. A patient should typically receive blood transfusions that match their blood type. When a patient is requested, blood type is not available at the time of the request; an ABO/Rh compatible group must be given. A blood substitution preference enables finding the best blood type allocation when there are many compatible blood types (Ana Torrado et al., 2022). ABO substitution is the term used to describe the use of a suitable blood group. Seventeen reference papers explored the impact of allowing ABO substitution during the transfusion process in a stochastic setting (see: John Blake et al., 2016 & D.M.S. Kumari et al., 2016; & A. Ahmadi et al., 2016; & Kartikeya Puranam et al., 2016; & Amir H et al., 2017; & Sima M et al., 2018; & Bayan Hamdan, et al., 2018; & Maryam Dehghani et al., 2019; & Pritha Dutta et al., 2019; & Seyyed-Mahdi, et al., 2019 & A. Pirabán, et al., 2019 & Suchithra Rajendran, et al., 2019 & Mohammad Arani, et al., 2019 & Samer Hamadneh, et al.,2021 & Mohammad Shokouhifar, et al.,2021 & NasurudeenAhamedN, et al.,2022 & Ana Torrado, et al., 2022). In addition, the ABO substitution was taken into account by Seyyed-Mahdi et al. (2019) and Nazanin Haghjoo et al. (2020), respectively, in fuzzy and forecasting contexts. Bayan Hamdan et al. (2018), providing ABO/Rh compatibility increases inventory management flexibility and reduces the amount of useless old units. In addition, it gives manufacturers a second chance to better match supply and demand. In contrast, John Blake et al. (2016) suggested that ABO-mismatched goods are not advised and are viewed negatively by doctors as providing subpar care.

Additionally, the patient might be linked to a priority for defining a transfusion policy. The policy aims to satisfy urgent and non-urgent demands to the greatest extent possible (Ana Torrado et al., 2022).

Fig 3: The six primary BSC processes

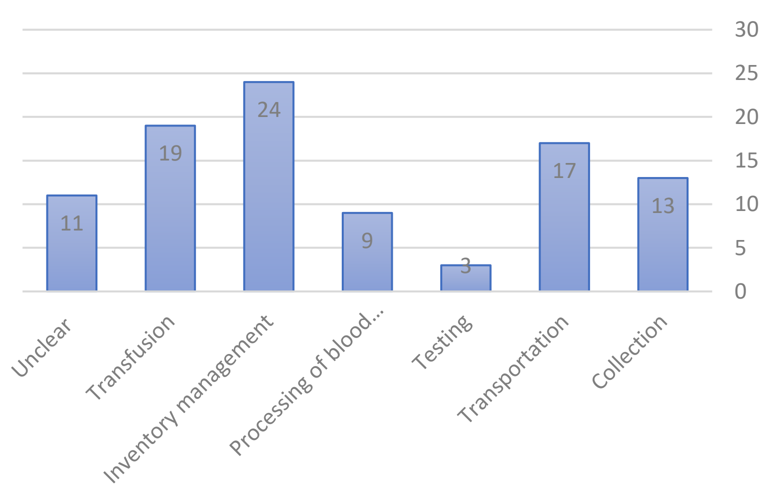


Table 6 The six primary BSC processes

BSC processes	No of studies	Reference
Collection	13	Mohammad Shokouhifar et al.,2021 & Mary Dillon et al., 2017 & John Blake et al., 2016 Sima M et al., 2016 & A.Pirabán et al., 2019 Ana Torrado et al., 2022 & Samer Hamadneh et al.,2021 & Bayan Hamdan et al.2019 A. Ahmadi et al.2016 & Ali Sibevei et al., 2022 Serkan Gunpinar et al., 2016 & Mohammad Reza et al., 2018 & Henrique L.F. et al., 2019
Transportation	17	Ke-Ming Wang et al., 2015; & Serkan Gunpinar et al., 2016; & Mary Dillon et al., 2017, & Ali Ekici et al., 2018 & Sima M et al., 2016; & Mary Dillon et al., 2017; & Seyyed-Mahdi et al., 2019 & Ganesh et al., 2014 & Mobasher et al., 2015; & Rabbani et al., 2017 & Ana Torrado et al., 2022 & Jihad Jemai et al., 2019 & Mohsen Naghipour et al., 2019 & Neil K. et al., 2019 & Henrique L.F., et al., 2019 & Kate Smith-Miles, et al., 2020 & Ali Sibevei, et al., 2022
Testing	3	Mohammad Arani et al., 2019 & Marzieh Eskandari-Khanghahi et al., 2018 & Ana Torrado et al., 2022
Processing of blood component	9	Sima M et al., 2018 & Mary Dillon et al., 2017 & Pritha Dutta et al., 2019 & Henrique L.F. et al., 2019 & John Blake et al., 2016 & Sima M et al., 2016; & D.M.S. Kumari, et al., 2016 & Ana Torrado et al.,2022 & Neil K. et al., 2019
Inventory management	24	Ana Torrado et al., 2022 & Neil K. et al., 2019 & D.M.S. Kumari et al., 2016 & Henrique L.F. et al., 2019 & Kate Smith-Miles, et al., 2020 & Ali Sibevei et al., 2022 & Pritha Dutta et al., 2019; & Seyyed-Mahdi, et al., 2019; & A. Pirabán et al., 2019; & Suchithra Rajendran et al., 2019; & Mohammad Arani, et al., 2019 & Samer Hamadneh, et al.,2021; & Mohammad Shokouhifar, et al.,2021; NasurudeenAhamedN, et al.,2022; & Sima M et al., 2016; & Shiva Moslemi et al., 2017 & Amir H et al., 2017 & Marzieh Eskandari-Khanghahi, et al., 2018; Maryam Dehghani, et al., 2019; & Mohsen Naghipour, et al., 2019; & Ali Ekici et al. 2018 A. Ahmadi et al., 2016 & Pritha Dutta et al., 2019 John Blake et al., 2016
Transfusion	19	Ana Torrado et al., 2022 & John Blake et al., 2016 & D.M.S. Kumari et al., 2016; & A. Ahmadi et al., 2016; & Kartikeya Puranam, et al., 2016; & Amir H, et al., 2017; & Sima M, et al., 2018; & Bayan Hamdan, et al., 2018; & Maryam Dehghani, et al., 2019; & Pritha Dutta, et al., 2019; & Seyyed-Mahdi, et al., 2019 & A. Pirabán, et al., 2019 & Suchithra Rajendran, et al., 2019 & Mohammad Arani, et al., 2019 & Samer Hamadneh, et al.,2021 & Mohammad Shokouhifar, et al.,2021 & NasurudeenAhamedN, et al.,2022 & Ana Torrado, et al., 2022 & Nazanin Haghjoo et al. 2020

4.4 Modeling and solution techniques

The modeling and solution approaches used in the reference publications are examined in this section. The modeling techniques can be divided into simulation, mathematical programming, and other techniques. Exact algorithms, heuristics, and metaheuristics are the solution methods considered.

4.4.1 .Criteria for assessing the BSC's performance

Total cost minimization and wastage/shortage minimization are the most common goals in the literature. Less frequently used criteria include the reduction of fixed/mobile CSs (Sahin et al., 2007), transportation/processing/inventory costs (Gunpinar & Centeno, 2016; Hamdan & Diabat, 2019; Rabbani et al., 2017), the number of regular orders (Blake & Hardy, 2014), travel time (Attari & Jami, 2018; Hamdan & Diabat, 2019), the percentage of days without stock (Ana Torrado et al., 2022).

Total costs primarily take into account the following terms: collection cost (e.g., Mary Dillon et al., 2017; & Marzieh Eskandari-Khanghahi et al., 2018; & Mohsen Naghipour et al., 2019), transportation cost (e.g., Mohammad Reza, et al., 2018; Hamilton C. Tsang et al., 2018; Absalom E. Ezugwu et al., 2019; Jihad Jemai et al., 2019) (see Kate Smith-Miles et al., 2020; & Ali Sibevei, et al., 2022). Ali Sibevei et al. (2022) proposed reducing the environmental impacts by (i) a penalty cost associated with the disposal of old blood products and (ii) carbon emissions from the fleet of cars.

4.4.2 .Techniques for mathematical programming

There are linear programming (LP) models and mixed integer linear programming (MILP) models for deterministic decision-making environments, respectively (see Sima M et al., 2016; & Shiva Moslemi et al., 2017; & Sepideh Ghasemi,2019; & Nazanin Haghjoo, et al., 2020). In studies that consider mixed integer nonlinear programming (MINLP) models, integerlinearization is used to transform MINLP models into MILP models (see Samer Hamadneh et al.,2021; Najafi et al., 2017).

The BSC literature uses specific optimization approaches frequently in the stochastic decision-making environment. Stochastic programming (SP) determines the best course of action when at least one parameter is described as a random variable. Consult the writings of Birge and Ana Torrado et al. (2022). Chance constraint programming (CCP), which implies uncertainty in a constraint indicating that it should be satisfied with a pre-specified probability, is one method of stochastic modeling issues (Ana Torrado et al., 2022). In order to model stochastic issues, two-stage and multistage programs with recourse are also employed. Data are treated as random in two-stage stochastic programming (TSSP) issues. First-stage judgments are made without having complete knowledge of the random data. After receiving all available information, second-stage decisions or remedial measures are made. The two-stage problem's linear programming counterpart is created by considering a finite number of scenarios on random data with associated probability (Neil K. et al., 2019).

A multistage setting (MSSP) can be added to the two-stage stochastic programming (Ana Torrado et al., 2022). Additionally, other works used the Markov decision process (MDP), stochastic dynamic programming (SDP), and queuing models (QM) to describe issues addressed in the BSC (e.g., Kate Smith-Miles et al., 2020; & Jihad Jemai et al., 2019; & Ali Ekici, et al., 2018).

Robust optimization (RO) is typically developed to optimize the supply chain's worst-case performance for unknowable decision-making conditions. Uncertain parameters in RO problems can be expressed as continuous variables or discrete scenarios using the scenario-based approach (see Ana Torrado et al., 2022). It is frequently believed for continuous situations that these uncertain parameters could be changed within a predetermined range called interval uncertainty (see Samer Hamadneh et al.,2021).

Fuzzy mathematical programming, sometimes known as FMP, has been widely used in contexts where fuzzy decisions are made. Some violations of constraints are permitted in FMP. Flexible and probabilistic fuzzy programming are both taken into consideration. Possibilistic programming considers uncertainties in objective function and constraint coefficients, while flexible programming addresses uncertainties on the right-hand side (see Mohammad Reza et al., 2018).

In most cases, studies that produced mathematical modeling use CPLEX or Gurobi software to find a solution. The software used is not classified under this category for brevity's sake. Only small-sized examples can be solved using exact approaches in an acceptable amount of time. Heuristic techniques are thus viable substitutes for discovering excellent answers in more extensive situations (Absalom E. Ezugwu et al., 2019). High-level ideas known as metaheuristics are used to explore search areas using various techniques. They are among the ten effective options for resolving optimization issues with uncertainty (Sima M et al., 2018). Variable neighborhood search (VNS), simulated annealing (SA), self-adaptive differential evolution algorithm (SDE), genetic algorithm (GA), and symbiotic organism search algorithm are the primary metaheuristics employed by the reference articles (SOS).

4.4.3 .Simulation methods

In addition to the heuristic mentioned above and exact solution methods, simulation is frequently employed in supply chain design to handle uncertainty (Ana Torrado et al., 2022). Discrete event simulation (DES) is the methodology most frequently commonly used in BSC literature (e.g., Hamilton C. Tsang et al., 2018; & A. Pirabán et al., 2019; & NasurudeenAhamedN et al.,2022). The BSC has also used methods like Monte Carlo simulation (e.g., Shiva Moslemi et al., 2017; & Sepideh Ghasemi,2019; & Nazanin Haghjoo et al., 2020) and system dynamics simulation (Mohammad Shokouhifar et al.,2021). Although there is no assurance that an ideal solution will be found, simulation models are ideally suited for portraying intricate stochastic systems. Combining simulation and optimization provides a method for managing difficult decisions in the BSC (Ana Torrado et al., 2022). A model that combines DES with a MILP model was presented by Ana Torrado et al. (2022) to support choices made in BSC production planning. A DES was used by Henrique L.F., et al, (2019). However, it was included in a particle swarm optimization (PSO) method. A simulation-optimization framework that incorporates metaheuristics, including threshold accepting (TA), tabu search (TS), differential evolution (DE), and harmony search, was proposed by Henrique L.F. et al., 2019. (HS).

Table 7 Modeling and Solution Techniques

Modeling and solution techniques	**No of studies**	**Reference**
Criteria for assessing the BSC's performance	13	Ke-Ming Wang, et al, 2015 & Ismail Civelek, et al, 2015 & Ana Torrado et al., 2022 & Mary Dillon et al., 2017; & Marzieh Eskandari- Khanghahi, et al., 2018; & Mohsen Naghipour et al., 2019 & Mohammad Reza, et al., 2018; & Hamilton C. Tsang et al., 2018; & Absalom E. Ezugwu et al., 2019; & Jihad Jemai et al., 2019 & Kate Smith- Miles et al., 2020; & Ali Sibevei, et al., 2022 & Kartikeya Puranam, et al, 2016
Techniques for mathematical programming	15	Sima M et al., 2016; &Shiva Moslemi et al., 2017; & Sepideh Ghasemi,2019; & Nazanin Haghjoo, et al., 2020 & Samer Hamadneh et al.,2021; & Najafi et al., 2017 & Ana Torrado et al., 2022 & Neil K. et al., 2019 & Kate Smith-Miles, et al., 2020; & Jihad Jemai et al., 2019; & Ali Ekici, et al., 2018 & Samer Hamadneh et al.,2021 & Mohammad Reza et al., 2018 & Absalom E. Ezugwu et al., 2019 & Sima M et al., 2018
Simulation methods	9	Ana Torrado et al., 2022 & Hamilton C. Tsang et al., 2018; & A. Pirabán et al., 2019; & NasurudeenAhamedN et al.,2022 & Shiva Moslemi et al., 2017; & Sepideh Ghasemi,2019; & Nazanin Haghjoo et al., 2020 & Mohammad Shokouhifar et al.,2021 & Henrique L.F., et al,2019

5. Conclusion

Managing the blood supply network is undeniably of paramount importance due to its critical impact on patient well-being and healthcare costs. This essay has delved into the extensive research conducted in the field of blood supply chain management, focusing on studies published between 2015 and 2022. Through a meticulous examination and categorization of this research, we have sought to contribute to the existing body of knowledge by providing a fresh perspective and evaluation of the state of the art in this domain.

Our analysis has highlighted several key areas within the blood supply chain that warrant attention and improvement. These include decision-making environments, supply chain design challenges, operational methods, decision models, problem-solving techniques, and data characteristics. By categorizing and scrutinizing research in these areas, we have aimed to shed light on both the progress made and the gaps that persist in this field.

Furthermore, it is important to emphasize the existing shortcomings and inadequacies in the current literature. This serves as a call to action for future researchers and practitioners to address these deficiencies and explore innovative approaches to enhance blood supply chain management.

In conclusion, this survey has not only provided a comprehensive overview of research on the blood supply chain but has also underscored the need for continued exploration and improvement in this critical area of healthcare logistics. As we move forward, it is our hope that this classification and critical evaluation will serve as a valuable resource for advancing the efficiency and effectiveness of blood supply management, ultimately benefiting patients and healthcare systems worldwide.

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