Modelling of the Collections Process in the Blood Supply Chain: A Literature Review

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Abstract

Human blood is a scarce resource and its role in healthcare is fundamental, with donated blood saving the lives of many on a daily basis. The blood supply chain is responsible for the transfer of blood from donor to the recipient, but the availability of such an invaluable resource as human blood is ultimately attributable to the many voluntary donors. Thus, the efficiency of the collection of donated blood is crucial to the downstream effectiveness of the blood supply chain. We provide a detailed review on the use of quantitative methods for the process of blood collection from donors. We describe the functional areas which are appointment scheduling, collection policy, crisis situation, donor demographics, location/clinic planning, staff utilisation and vehicle routing. Furthermore, we analyse the existing literature with regards to methods, modelling objectives and the planning levels such as strategic, tactical and operational. Finally, we break down the articles into whether or not case studies lead to the implementation of the methods in practice. In total, we review 46 relevant publications on the intersection between OR/MS and other disciplines. We use our presented framework to categorise the existing approaches and highlight gaps such as scheduling of both staff and appointments for blood donation clinics.

Keywords: blood supply chain, blood collection, operational research, healthcare modelling, literature review

1 Introduction

Blood is a scarce resource and its role in healthcare is fundamental, with donated blood saving the lives of many on a daily basis and on a global scale. It is estimated that 85 million blood transfusions are carried out annually across the globe, which translates to nearly 3 blood transfusions per second [15]. The blood supply chain is responsible for the transfer of blood from donor to the recipient, but the availability of such an invaluable resource as human blood is ultimately attributable to the many voluntary donors. Blood is a complex product due to its perishability and compatibility requirements between donor and patient. The blood supply chain comprises of four echelons: (Osorio et al. [37])

- **Collection:** This is the beginning of the blood supply chain and involves either fixed or mobile blood donation clinics, or a combination of both. Blood products may be collected in the form of either an individual blood component via a process called apheresis, or whole blood which is the most common form of donation. From a donor's perspective, a clinic typically follows the process displayed in Figure 1, with queues often arising between the activities (which will be referred to in this literature review as workstations). Eligibility screening is necessary as there are many restrictions on who may donate blood [47]. Screening often becomes a prolonged process with many health-related questions and a test for iron levels within the donor's blood. The collection echelon ends with all blood donation units transported to a blood processing centre.

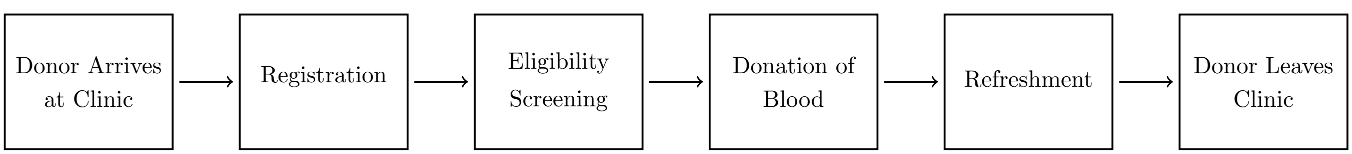

Figure 1: Typical Path of a Donor at a Donation Clinic

- **Production**: This takes place at a blood processing centre, where donated units of blood are tested and separated into various components (red blood cells, platelets and plasma) as required. The production of platelets depends on the amount of time since the donation, as platelets must be separated from whole blood shortly after collection. This echelon ends with blood being packaged ready for distribution and moved to storage.

- **Inventory:** Storage of blood products may either take place at a blood processing centre or a stock-holding unit. Each type of blood product has unique shelf-lives and specific storage requirements, with platelets being the most complicated; platelets must be kept in an agitated state at ambient temperature for a maximum of ≈ 5 days.
- **Distribution:** This echelon consists of the preparation of orders of blood products and the transportation of such orders to the respective hospitals. Decisions involved include the dates and blood types of dispatched products, due to blood compatibility and possible limited inventory.

Currently, the vast majority of literature concerns the inventory stage (Osorio et al. [37]) with little in-depth research carried out on the collections process. Therefore, the aim of this review is to evaluate the existing literature that deals with modelling of blood collection, provide a detailed classification of the selected articles, and thus identify any areas that may benefit from further research.

The remainder of this literature review is structured as follows. In Section 2, we describe how we conducted the structured search and provide an overview of previous literature reviews. In Section 3, we describe the relevant characteristics of blood collections. We demonstrate how the retrieved articles from Section 2 were classified into the various categories. Section 4 closes our literature review with conclusions.

2 Selection Criteria and Previous Reviews

2.1 Selection Criteria and Search for Relevant Literature

We search for journal publications from the Clarivate Analytics Journal Citation Report (JCR) in the subject categories of Health Policy and Services (HPS), Medical Informatics (MI), Industrial Engineering (IE), as well as Operations Research and the Management Sciences (OR/MS). These categories are selected due to the complex nature of the blood supply chain, with modelling of such arising from various fields and disciplines. The rationale for choosing these categories is to capture literature from a range of perspectives, whether it be policy decisions and service improvement (HPS), information systems and data mining (MI) or quantitative healthcare engineering (IE). The inclusion of these categories, together with OR/MS, yields a thorough analysis of research contributing to improvement of the collection echelon of the blood supply chain.

Using a structured search string, Scopus provided a base set of articles with the search mainly focusing on “blood collection” and “blood donation”. The search excludes all publications before 1996 and produced a total of 106 results in February 2019. All articles that did not specifically refer to the collections process were considered irrelevant, as were all articles that did not contain quantitative analysis or discuss optimisation of the blood supply chain. A forwards and backwards search from relevant articles was then conducted (as suggested by Webster & Watson [50]) and all relevant results collated. In carrying out our forwards search, we not only retrieved journal publications citing the articles from the original search but also a PhD thesis (van Brummelen [13]) which we decided to include in our final (relevant) set of publications. Collectively, this gives a total of 46 articles, as shown in Figure 2.

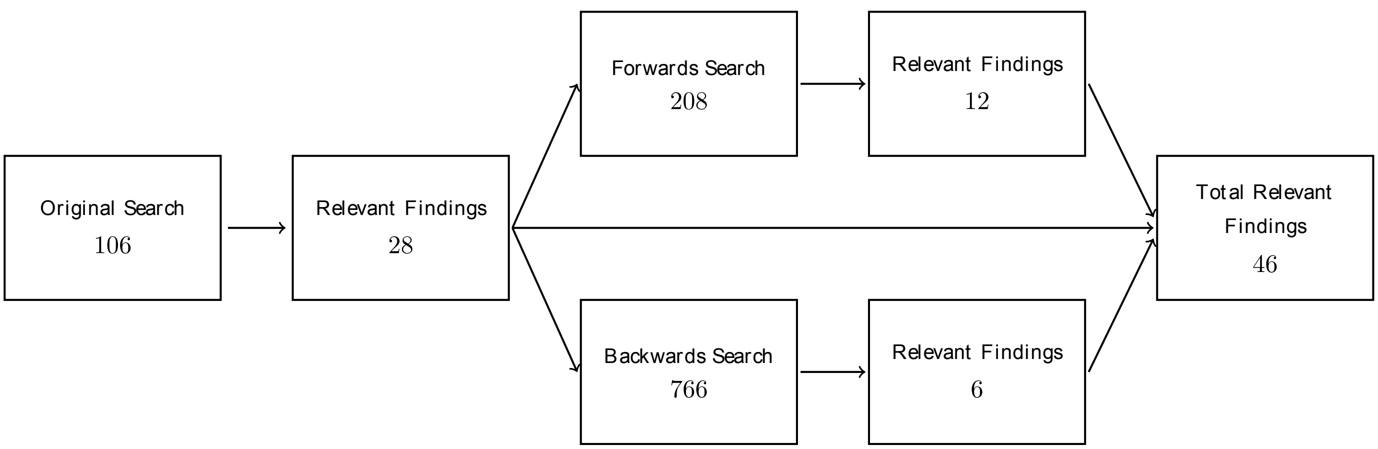

Figure 2: Scopus Search Results

2.2 Previous Reviews

There is a vast amount of literature that addresses modelling of the blood supply chain, however, only a minority of articles focus on the collection echelon. From our findings, there are four relevant reviews that address modelling of blood collection from donors; [6,8,9,37]. The most specific of these is written by Baş Güre et al. [6] who state that there are still several aspects of blood collection that have not yet been explored from an optimisation perspective, but specifically focus on donation appointment scheduling.

Baş Güre et al. also published another review [8], prior to the above article, which studies existing literature surrounding the blood supply chain in general, categorising by echelon and perspective of research. Similarly, Osorio et al. [37] provide a review of the whole blood supply chain, with a brief insight into the literature considering the collections process, categorisation of its planning decisions, and quantitative models of the process. In both reviews, the section addressing collections however is significantly smaller than those regarding other echelons of the supply chain, indicating that there is less existing research covering this particular echelon.

Lastly, Beliën and Forcé [9] deliver a review of the whole blood supply chain also, but instead categorise by methods used, blood product considered, etc. rather than by echelon of the supply chain. This makes it difficult to identify areas within sections of the blood supply chain that require further research.

Our review differs from these previous reviews as it provides a detailed taxonomy of articles, specifically focussing on the collection echelon of the blood supply chain. It includes all existing research on blood collection that consider an OR approach, including those from an interdisciplinary perspective, and provides an up-to-date analysis of surrounding literature due to the significant increase in publications within this field over recent years, as demonstrated by Table 1. Thus, our literature review presents an in-depth discussion of current literature on the collections process and clearly identifies areas that require further research.

3 Classification of Literature

Employing the selection criteria, a total number of 46 articles were retrieved and considered relevant for this review. The articles can be categorized by publication year as given in Table 1. The table reveals that this field of research is becoming increasingly popular, since 76% of the relevant articles were published within the last five years. Earlier publications mainly consist of more simplistic statistical analyses, such as the impact of sharing blood donor deferral registries to streamline donation clinics [20]. However, in 1996 Jacobs et al. [29] published an integer programming method to advise the American Red Cross on whether to relocate a permanent facility. In more recent years, integer programming methods remain popular in optimising blood collection, in addition to many other OR methods including simulation and machine learning. The dramatic increase in research in optimisation of blood collection may be attributed to the technological advancements which enable the growing range of OR methods to be utilised effectively.

Table 1: Number of Articles by Publication Year

Time Period	Before 2005	2005–2007	2008–2010	2011–2013	2014–2016	2017–2019	Total
Number of Articles	2	2	2	5	14	21	46

The articles can also be classified by geographic location, as seen in Table 2. Here, articles are classified under either the location of any mentioned case studies, or that of the first named author. The majority of research in blood collections has been based in Asia, and most of these are in developing and emerging nations (such as Iran) and consider the blood collections process in the event of disasters (from natural or man-made causes) e.g. earthquakes. However, there is a lack of research regarding the blood supply chain in the event of disasters from elsewhere in the world, and this suggests that there is further research to be done to aid the blood services in countries who may face similar circumstances. There are a significant amount of articles concerning modelling of blood collection from Europe and America (North and South America collectively) which indicates that this is indeed a worldwide issue.

Table 2: Number of Articles by Continent

Continent	America	Asia	Europe	Rest of World	Total
Number of Articles	9	24	12	1	46

The articles may also be classified according to their respective JCR (Journal Citation Report) category to illustrate the approach and perspective of the research. The four subject categories are Health Policy and Services (HPS), Industrial Engineering (IE), Medical Informatics (MI) and Operations Research and Management Sciences (OR/MS). Only a total of 29 articles are listed in

Table 3, with the remaining 16 articles from other journals outside of these categories (all of which are from the forwards and backwards search) reinstating the multi-disciplinary nature of blood collection. The OR/MS category is clearly the most popular of the four categories; this conveys the usefulness of OR methods to tackle modelling of blood collection from donors.

Table 3: Articles by JCR Category

JCR Category	Articles	Total
HPS	[3, 20, 40]	3
IE	[6, 21, 34, 36, 37, 41, 44]	7
MI	[19, 49]	2
OR/MS	[5, 7, 9, 10, 14, 18, 22, 24, 26, 29, 30, 33, 38, 43, 45, 46, 51]	17

In the next subsections, a classification framework for these articles will be provided, categorising into functional areas, methods and approaches, planning decision level, and whether a case study was incorporated.

3.1 Functional Areas Considered

We now classify the articles by the functional area in which the research aims to improve/target. The functional areas have been organised into the following categories:

- **Appointment Scheduling:** All articles that discuss an appointment scheduling policy, framework, or optimisation of appointments.
- **Collection Policy:** This covers all research and analysis of the way in which blood is collected from donors, including eligibility/deferral of donors and also the collection strategy.
- **Crisis Situation:** This involves all research into the blood supply chain from the perspective of a crisis occurring and emergency aid being required e.g. natural disasters such as earthquakes.
- **Donor Demographics:** This includes all analysis and research of donor demographics such as donor behaviour, location, age, blood type, etc.

- **Location/Clinic Planning:** This category includes all research which considers the location of either temporary or permanent facilities used for blood collection (mostly location of donation clinics). Both the allocation of clinics and relocation of facilities are categorised under this.
- **Staff Utilisation:** This category includes all articles which consider the allocation of staff to clinics and also analysis of staff level requirements and skill mix.
- **Vehicle Routing:** All articles that consider routing of vehicles that transport blood and resources for blood collection.

Note that articles which do not fit into any of the above categories are literature reviews and thus not proposing any particular methods or action.

Table 4: Functional Areas of Research

Functional Area	**Articles**
Appointment Scheduling	[3, 7, 13, 36]
Collection Policy	[3, 5, 19, 20, 23, 26, 33–35, 38, 40]
Crisis Situation	[18, 21–23, 25, 30, 32, 46, 48]
Donor Demographics	[2, 3, 19, 22, 31, 43, 49]
Location/Clinic Planning	[2, 4, 5, 14, 16–18, 21–27, 29, 30, 34, 39, 42–46, 48, 51, 52]
Staff Utilisation	[2, 3, 11, 13, 49]
Vehicle Routing	[24, 32, 36, 41, 42, 45]

3.1.1 Appointment Scheduling

Appointment Scheduling is the least popular category, as revealed by Table 4. While many donation sites worldwide accommodate for unbooked or "walk-in" donors, appointment systems provide an opportunity to control the arrival patterns of donors and better manage resources and inventory. Mobasher et al. [36] consider how many donations should be collected within certain time intervals in accordance with vehicle routing to maximise donations viable for platelet production. Alfonso et al. [3] place more of an emphasis on appointment strategies regarding frequency of apheresis donations throughout the day, whilst Baş Güre et al. [7] focus on pre-allocating appointment slots to each blood type at a permanent facility. Van Brummelen [13] considers the combination of appointments and "walk-ins" and produces an optimal appointment schedule based on minimising waiting times for donors.

More generally, the literature surrounding appointment scheduling in healthcare neglects mainly strategic decisions but also most tactical decisions; according to Ahmadi-Javid et al. [1] the vast majority of publications concerning optimisation of outpatient appointments focus on an operational level. Contrastingly, the publications focusing on blood collection take a more tactical approach. Ahmadi-Javid et al. [1] also discuss the increasing interest in appointment scheduling, as over 73% of the publications considered in their review were produced between 2012 and 2016 (the most recent at the time of publication). Despite this, there is still a significant lack of research applied to blood donor appointment scheduling.

There is also a lack of research that considers combining various aspects of appointment scheduling. Reducing waiting times, matching supply to demand (including blood type specific demand) and managing donor arrivals are all key elements of effective and efficient blood collection, yet research within appointment scheduling often focus on just one of these goals.

3.1.2 Collection Policy

Collection policy is considerably widely researched, with a significant amount of these articles considering how many units of blood should be collected at a clinic [5, 23, 26, 33–35, 38, 40]. This is considered from a variety of perspectives, such as the number of mobile clinics to deploy [26], how much to collect at each clinic under various scenarios [5], or when to stop collecting each day [35]. Lowalekar & Ravi [34] use the Theory of Constraints (TOC) thinking process to evaluate the collections process associated with a blood bank in Chennai, India, to identify areas for improvement in the collection policy and thus improve inventory management. Donor deferrals are observed [3,19,20,34], with Custer et al. [19] evaluating blood safety and policy decisions to assess the impact of deferrals on inventory. Various methods of blood product collection are also studied [3, 38, 40], with Osorio et al. [38] optimising the balance between whole blood and apheresis, considering cost and the number of donors required to reach demand.

3.1.3 Crisis Situation

Of the nine articles that address the blood supply chain in the event of a crisis situation, the majority of these also include location/clinic planning [18, 21–23, 25, 30, 46, 48] with the remaining article focussing on vehicle routing [32]. This is due to the importance of facilities (collection and processing) being located in an accessible area for a responsive and reliable supply chain. The aims of these articles vary from minimising transport time [21, 22] to ensuring fairness in the distribution of blood products [18]. Most of the publications include a case study [18, 22, 23, 25, 30, 46] with all of these based on the scenario of an earthquake in various cities in Iran. There is a lack of research within this area from elsewhere in the world, particularly studying disasters with anthropogenic causes.

3.1.4 Donor Demographics

Donor demographics and behaviour have a significant impact on the success of the collections echelon, and while many articles indirectly consider these aspects, only seven directly incorporate such aspects into their models. Alfonso et al. consider donor behaviour such as generosity and availability to inform their location-allocation model [2] and simulation model [3]. Custer et al. [31] study donor demographics regarding likelihood of donor deferrals, while Testik et al. [49] study donor arrival patterns. The location of donors is considered in various location planning models [2, 22, 43] to inform where to locate clinics to ensure the required amount of blood will be collected. Lastly, Lee & Cheng [31] classify disparities in donor behaviour to identify possible causes of decreasing donations and predict donors' intentions.

3.1.5 Location/Clinic Planning

Location and clinic planning is the most popular category within the selected literature. This is unsurprising since the success of a clinic depends heavily on the location, which is ideally easily accessible and within a given radius of a large amount of regular donors in order to meet the collection targets. The majority of articles in this category detail a location-allocation problem [2, 4, 5, 16, 18, 21–27, 29, 30, 39, 42–46, 48, 52] i.e. deciding the location of both mobile and fixed donation clinics, and often also attempt to minimise the costs involved with moving clinics and transportation of blood products. The next most popular area of research within this category is the planning of clinics, such as the explicit scheduling of clinics at locations that are already assigned [2, 45]. Several articles in this category either focus on relocating or establishing a new facility such as a blood centre or stock holding unit [10, 16, 29, 44], whilst the comparison of effectiveness of mobile and fixed clinics is also considered [3]. Centralisation of a regional blood service is discussed in the literature, with various levels of centralisation considered and analysed by Osorio et al. [39].

3.1.6 Staff Utilisation

Staff Utilisation is another category lacking in research with only five articles exploring this area. All of these propose slightly different approaches, but nearly all deal with determining the general staffing requirements for donation clinics in order for the blood services to reach their targets for donor satisfaction and volume of collected blood. Both Alfonso et al. [3] and Blake & Shimla [11] consider various configurations of clinic staff and the impact of these on donor waiting times and service level, with the former using simulation and the latter using queueing theory. Both aim to keep costs and queues to a minimum, and along with Testik et al. [49], intend to better inform policy. However, Testik et al. approach the problem from the perspective of donor arrivals and the effect of this on workforce utilisation. The goal of this is to identify patterns in donor behaviour (through data mining methods) and determine an adaptive workforce with varying numbers of staff throughout the day to better cope with changes in donor arrivals.

Van Brummelen [13] presents an ILP model to optimally assign varying length shifts to staff to best cope with donor arrival patterns. Van Brummelen also considers intra-day scheduling of staff across the stations within the clinic to minimise donor waiting times and staff hours worked. This model is based on fixed clinic sites, whereas Alfonso et al. [2] consider staff scheduling for mobile sites also. Alfonso et al. [2] present a two-stage model in which the latter produces a staff schedule for each clinic. However, the model does not include intra-day scheduling. Furthermore, none of the articles consider intra-day scheduling regarding employee breaks or closure of clinic for lunch and how this may effect donor flow. This lack of research in scheduling of staff at donation clinics is surprising, since a lack of efficient staffing can have a massive impact on both donor satisfaction and volume of collected blood.

3.1.7 Vehicle Routing

In all publications under this category, the principle aim is to minimise the distance travelled by vehicles associated with the collections echelon, though the motivation behind this aim varies. Several articles discuss the importance of vehicle routing in order to maximise platelet production [36, 41, 42] due to its perishable nature. Şahinyazan et al. [45] and Gunpinar & Centeno [24] both utilise vehicle routing in order to maximise the number of blood donations collected, while Lodree et al. [32] determine the optimal routes during the response phase following a large-scale disaster.

3.2 Methods

Since this review focusses on OR methods, a detailed overview about the methods and solution approaches is given in Table 5. The approaches are categorised into Data Mining and Machine Learning, General Statistical Analysis, Goal Programming, Heuristics, Integer Programming (includes mixed integer programming), Queueing Theory, Qualitative, Simulation, and Stochastic Modelling. Note that any previous literature reviews are assigned to the Qualitative category, and that the category Statistical Analysis includes articles that incorporate probability distributions or forecasts of certain aspects such as blood product demand or donor behaviour.

The table reveals that (mixed) integer programming is a commonly used modelling and solution method in the field of blood collections. All of the articles that use this method, utilise it to solve an allocation problem: either of location, appointments, staff shifts, or routes of vehicles, with the objective function mostly being to minimise costs and to maximise donor satisfaction or blood collected. This conveys why integer programming is the most popular approach, since the effective allocation of clinic locations, donor appointments and vehicle routes are fundamental to the success of a blood supply chain.

Stochastic modelling is also a popular method in optimisation of collection of blood, and mostly used alongside an integer program [5, 18, 22, 24, 26, 38, 40, 42, 43, 51, 52]. This is due to the stochastic nature of the blood supply chain, particulary regarding both the demand of blood products and supply

Table 5: Methods

Methods	Articles
Data Mining and Machine Learning	[31, 36, 41, 49]
Statistical Analysis	[2, 19, 20, 33, 34]
Goal Programming	[16, 25]
Heuristics	[13, 27, 32, 33, 36, 39, 41, 42, 45, 48]
Integer Programming	[2, 4, 5, 7, 13, 14, 17, 18, 22–24, 26, 29, 30, 32, 36, 38, 40, 42–45, 48, 51, 52]
Queueing Theory	[11, 13, 49]
Qualitative	[6, 8, 9, 34, 37]
Simulation	[3, 10, 13, 19, 33–35, 40, 46]
Stochastic Modelling	[5, 18, 21–26, 38, 40, 42, 43, 46, 51, 52]

from donors. A significant amount of these publications present a robust optimisation approach [5, 18, 22, 24, 25, 43, 46, 51, 52] which mostly consider the uncertainty in parameters such as donor arrival, costs and demand. For instance, Zahiri et al. [52] propose a strategic robust possibilistic programming model to ensure the results are still relevant and applicable over the long planning horizon, minimising the effect of changes in parameters over time. Many of these publications focus on disaster relief [18, 21–23, 25, 46] and utilise stochastic modelling to create a more robust blood supply chain, to ensure effectiveness even in the midst of an emergency.

Heuristic techniques involve algorithms that seek approximate solutions quickly, and these are a frequently used mathematical method within the selected literature. These are also often used alongside integer programming methods [32, 36, 42, 45, 48], and in this case are mostly integer-programming-based algorithms. Heuristics are also used with statistical methods to aid a primarily simulation approach [33], as Lowalekar et al. use a gradient search-based heuristic to identify the optimum policy parameters for their model. Van Brummelen [13] uses a heuristic algorithm to allocate optimal appointment slots throughout the day. Only one of these articles uses heuristics as their primary method [27] - Hsieh et al. propose a solution to a location-allocation problem regarding donation clinics, and here they use a sorting genetic algorithm to search for the Pareto set to solve the multi-objective problem. A common theme in the utilisation of heuristic algorithms is vehicle routing problems [32, 41, 42, 45] due to the ability of such algorithms to analyse a vast amount of possible routes quickly; this efficiency is beneficial to many other problems within the blood supply chain, as such problems are often very complex with a large amount of parameters and variables.

Simulation is widely used to analyse and optimise the blood collections process. However, some of the articles in this category only use simulation as support or stochastic evaluation of the mathematical model, and it is therefore not the primary method in use. For example, simulation is used as a way of evaluating the implementation of a proposed model [13, 33, 34, 46], evaluating a current systems performance [3], or to generate scenarios for a mathematical programming formulation [2]. The only articles in which simulation is used as the primary method to optimise blood collections are [10,19,35]. Blake et al. [10] use simulation to determine the impact of the addition of a stock holding unit in a given region in Canada, Lowalekar & Ravichandran [35] use simulation to compare two potential new collection policies against each other and indeed against the current policy, and finally, Custer et al. [19] evaluate the cost of blood per unit using simulation.

Data mining and machine learning techniques are mainly used to support other mathematical methods. For instance, Mobasher et al. [36] and Özener & Ekici [41] utilise clustering algorithms to assist with vehicle routing problems. Meanwhile, Testik et al. [49] and Lee & Cheng [31] use data mining and clustering methods to evaluate donor behaviour such as likelihood to donate and arrival patterns at clinics. These methods provide an innovative approach to modelling of the blood collections process as they offer the opportunity for donation clinics to be planned in alignment with the respective donorbase of a given region, regarding the planning of location, capacity and staff.

3.3 Model Objectives

In what follows, we will break down articles which provide a mathematical model of the blood collection problem into various objectives; such objectives are clearly identifiable in the case of some methods, such as integer programming. For other methods, we identify objectives from the authors detail on the aims of their research, and outcomes of their model. A total of 33 articles are found to specify an objective to be maximised or minimised, with the most popular of these detailed in Table 6 whilst Table 7 displays the articles which share a common objective. The four objectives are defined as the following:

- **Minimise cost:** Models that aim to lessen any costs, from clinic operation to transportation costs

- **Maximise blood:** Any models that seek to maximise the total amount of blood collected.
- **Minimise time:** This includes the minimisation of time used - either regarding a specific aspect (such as transportation), or that of the whole blood supply chain.
- **Minimise distance:** Any models that aim to decrease distance in some way, ranging from distance travelled to distance between facilities.

Table 6: Popular Objectives

Objective	**Articles**
Minimise Cost	[4, 5, 11, 13, 14, 16–18, 21–23, 25, 26, 29, 30, 38–40, 42–46, 48, 51, 52]
Maximise Blood	[22, 36, 42, 45]
Minimise Time	[4, 5, 21–23, 26, 30, 41, 44, 48]
Minimise Distance	[16, 17, 24, 46]

Both Table 6 and Table 7 clearly show that the most popular objective is minimisation of cost. This is unsurprising since most blood services are non-profit organisations, and donors are usually voluntary and non-remunerated. While many articles aim to minimise the cost of the collection echelon in general, or even the whole blood supply chain, some focus on more specific costs. An example of this is the cost of clinic operation; Salehi et al. [46] seek to minimise the costs of establishing permanent blood centres, while Blake & Shimla [11] aim to minimise costs associated with staffing.

The minimisation of time is the second most popular objective, which is typically due to the perishable nature of blood. This objective is often considered alongside minimisation of costs as the two are closely linked, especially regarding transportation and staffing. Some articles present a model which aims to minimise the length of the blood supply chain, across all echelons i.e. reduce the time

Table 7: Common Objectives

Objectives	**Articles**													
	[4]	**[5]**	**[16]**	**[17]**	**[21]**	**[22]**	**[23]**	**[26]**	**[30]**	**[42]**	**[44]**	**[45]**	**[46]**	**[48]**
Minimise Cost	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Maximise Blood						✓				✓		✓		
Minimise Time	✓	✓			✓	✓	✓	✓	✓		✓			✓
Minimise Distance			✓	✓									✓	

blood products spend in the system, from donation to distribution at a hospital. For example, Attari et al. and Arvan et al. [4, 5] present this goal in their respective models. However, other models focus on a specific attribute such as transportation time [21–23,30,41,48] - distance is closely related to this, which may be the reasoning behind fewer articles detailing the minimisation of distance as a main objective. Although, minimising distance may also concern factors other than transportation, such as fairness in distances between blood centres and hospitals within a given region [16]. Additionally, Şahin et al. [44] aim to minimise the total demand-weighted distances both from donation clinics to blood processing centres, and from blood processing centres to hospitals.

Three articles detail the maximisation of blood collected as an objective, though from varying perspectives. Rabbani et al. [42] wish to maximise the amount of donations that remain viable for platelet production, while Şahinyazan et al. [45] aim to maximise the amount of blood collected while optimising vehicle routing between mobile clinics. Finally, Fazil-Khalaf et al. [22] seek to collect as much blood as possible in disaster situations. Though each blood service requires a significant amount of blood to support demand, perhaps this objective is less popular due to overcollection of blood leading to wastage of blood products.

Aside from the objectives listed in Table 7, various objectives were discussed individual to the following articles [2, 7, 34, 36, 49]. Since the functional area of [7] is appointment scheduling, in this article, Baş et al. focus their objective function on balancing the production of each blood type among days to minimise wastage of blood. Alfonso et al. [2] aim to minimise the system overtime, whilst maximising the donor service level. Mobasher et al. [36] focus on minimising the total working time along with the blood supplied by other regions (and thus incurring a cost). Lowalekar & Ravi [34] concentrate on inventory-related objectives and aim to minimise both shortages and outdates of blood products, whilst Testik et al. [49] focus on clinic operation related objectives such as maximisation of staff utilisation and minimising donor wait.

A wide variety of objectives are covered in the selected literature, and whilst minimising costs is of high importance to a blood service, donor satisfaction is crucial and often overlooked. As discussed above, the minimisation of donor waiting times and service level has been considered, though minimally. The matching of supply and demand is vital to the success and effectiveness of a blood supply chain, and there is little optimisation of this considered in the literature, as it is usually indirectly - this implies that further research which places matching supply and demand as a main objective would be of great benefit to blood supply chains worldwide.

3.4 Planning Decision Levels

The selected articles can be categorised by the planning decision level that they discuss; namely *strategic, tactical or operational (offline or online).*

Table 8: Articles by Planning Decision Levels

Planning Decision Level	**Articles**
Strategic	[2, 4, 5, 10, 14, 16–23, 25, 29–31, 33, 34, 39, 40, 43, 44, 46, 48, 51, 52]
Tactical	[5, 7, 13, 22, 23, 26, 27, 32, 36, 38, 41, 42, 45, 52]
Operational	
Offline	[2, 3, 7, 11, 13, 24, 36, 40, 45, 49]
Online	[7, 13]

As described by Hulshof et al. [28], strategic planning 'addresses structural decision making' and involves the decisions which help to develop and improve an organisation, more specifically in our case, a blood service. This is therefore typically over a long planning horizon. As shown in Table 8, the majority of the articles deal with strategic planning decisions. This is due to the vast number of articles that deal with locational planning and collection policy, as changes to these are typically implemented incrementally, and over a long period of time.

Tactical planning 'translates strategic planning decisions to guidelines that facilitate operational planning decisions', and often involves the coordination of operations within an organisation, as described by Hulshof et al. [28]. These decisions essentially focus on the 'what, where, how, when and who' of a given process. A total of nine of the selected articles fit into this category, and these are mainly either appointment scheduling or vehicle routing problems - these types of problems are often solved by providing a framework for the blood service to implement, or a decision support tool.

Operational planning is typically on a short-term basis, involving the execution of a blood service's processes; this planning decision level is further categorised into offline and online planning. Operational offline decisions are those that are made in advance of a process being carried out, such as assigning a resource to a donor, while operational online decisions are 'control mechanisms that deal with ... reacting to unplanned events' [28] during the process. All of the articles in the operational planning category are also in the operational offline planning subcategory, with only two also being in the operational online planning subcategory. This illustrates the need for processes to be well-prepared and organised in advance of starting a donation clinic, but also online decisions may need to be made regarding sickness of staff, appointment cancellations and prioritisation of donors.

Due to the complex nature of the blood supply chain, all planning decision levels are important and necessary. However, strategic planning allows for perhaps the most significant improvements towards a more effective and efficient supply chain, as long-term goals are able to be realised, such as the alignment of demand and supply.

3.5 Case Studies and Implementation

A total of 32 of the articles (70%) include a case study, with real-life data from a chosen blood service, as seen in Table 9. Several of these articles are of research motivated by a specific blood service, with the aim of any findings being implemented if proven effective, or to inform future policy.

Table 9: Articles by Case Study Inclusion

Case Study Included	**Articles**
Yes	[2, 3, 5, 7, 10, 11, 13, 14, 18–20, 22–27, 29, 30, 33–36, 38, 39, 43–46, 49, 51, 52]
No	[4, 6, 8, 9, 16, 17, 21, 31, 32, 37, 40–42, 48]

Only 14 of the articles did not present a case study within their research - note that the 4 previous literature reviews are included in this category, and aside from these, the remaining articles propose findings which are either tested on hypothetical data/situations or simply presented as theoretical arguments.

The majority of selected publications presented a solution which could possibly be implemented in real-life scenarios, yet only three of these articles specifically stated that their proposal had either been implemented or are likely to be implemented [14, 29, 40]. These findings are similar to that of Brailsford et al. [12] who state that 'levels of implementation for models in healthcare OR are very small indeed'. However, this figure may not be a true representation of the implementation of the current research, due to the possibility that the timeline of many projects may have ended before implementation could be carried out, and thus the corresponding article would have no mention of such.

4 Conclusions

This review has focussed primarily on the analysis and optimisation of the collections echelon of the blood supply chain, as there is a distinct lack of existing reviews providing an extensive and recent evaluation of this particular field of research. We developed a categorisation framework to distinguish methods, functional areas and various other aspects of existing research, and this provides a clear classification of the literature surrounding blood collections. This enabled us to identify any areas that require further research.

Perhaps the most notable area which calls for more in-depth research to be conducted is that of resource planning at blood donation clinics, and more specifically workforce planning. Presently, very few publications explore this (within our literature search) with most simply analysing the levels of required staff. Van Brummelen [13] does consider intra-day scheduling of staff and varying shift lengths but only for fixed clinic sites. Only one model that explicitly generates a staff schedule for mobile donation clinics [2], but this does not consider intra-day scheduling. Not only does the assignment of staff to clinics require further research, but also the scheduling of staff throughout a day, especially considering staff breaks and how to mitigate the effects of this on the donor waiting times. Intra-day scheduling is of great importance as it can help to improve donor service level, reduce waiting times and increase productivity, through utilising the workforce in alignment with varying donor behaviour throughout the day.

Appointment scheduling is also lacking in research within optimisation of the collection of blood, despite appointments enabling clinics to have some control over queues and donor arrivals. In the existing literature, the research tends to focus on one aspect of appointment scheduling such as apheresis donations, blood types, or aligning appointments with transportation of collected units. However, appointment scheduling provides the opportunity to not only control inventory in regards to volume and blood type, but also to manage the donor flow through a clinic via analysis of frequency of appointment slots. There is much research to be undertaken that marries all of these important aspects together.

Both the scheduling of staff and appointments have great impact on the efficiency of a clinic and donor satisfaction. Due to donors (in most cases) being volunteers and non-remunerated, it is vital to maximise the experience of donors as far as possible i.e. minimisation of queues, efficient service, convenient location and appointment time, etc. Future research within this field should place donor satisfaction at the forefront of its aims and objectives, as the success of blood supply chains ultimately rely on the many generous donors worldwide.

Matching supply and demand is the goal of any supply chain, but achieving this goal is of utmost importance to the blood supply chain, with failure to do so resulting in potentially critical consequences. Despite this, matching the supply and demand of blood is often neglected or only indirectly considered. Whilst many publications account for demand being satisfied, there is a significant lack of research regarding overcollection of blood as this leads to avoidable wastage of invaluable products.

Another area which has potential for further research to be carried out is the effect of disasters on the blood supply chain. At present, models that consider a robust and effective blood supply chain in crisis situations are only from Asia and concerning earthquakes. However, the rest of the world would also greatly benefit from conducting such research regarding their blood services as both natural and human-made disasters occur worldwide and have the potential to cause devastating effects and mass casualties.

In conclusion, as human blood is an invaluable and scarce resource which is essential to modern healthcare, the blood supply chain is vitally important globally. Since the success of the blood supply chain is ultimately dependent on voluntary donors in most parts of the world, further research into the collection of donated blood is imperative to reduce wastage and shortages of blood, and increase the effectiveness and efficiency of blood services.

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