Optimizing Inventory Management in Blood Supply Chains: A Literature Review

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Abstract

Blood Supply Chain Management is highly critical as ensuring the availability of the right blood type at the right demand point, in the right quantity, at the right time is a matter of life and death. The overall objective of this study is to explore the optimization approaches in inventory management of blood supply chains. A review of literature has been carried out to investigate different optimization approaches and management concepts towards blood inventory optimization while maximizing the service levels and minimizing discard rates. In the process of reviewing literature, initially 43 studies published between 2000 and 2019 were analysed through the keywords search and 19 papers were selected which were directly related to the area of study. A framework was developed by summarizing optimization techniques used; factors and complexities affecting blood inventory performance were identified and analysed. This paper includes state of the knowledge, potential research areas, and gaps that are available in this arena as a guidance for future researchers in this field. As further research, it is suggested to explore the behaviour of inventory management practices of multi-product, multi-echelon and perishable supply chains with highly uncertain demand and supply.

Keywords:
Optimization, Blood Supply Chains, Inventory Management

1. Introduction

Collection, production, inventory, and distribution are the main stages of blood supply chain management. The products in blood supply chain management are whole blood, red blood cells, blood platelets, blood plasma, and frozen blood. Shelf lives of these products range from five days (platelets) to one year (Frozen Plasma). The main challenges in the Inventory Management of blood supply chains are due to the complexities brought by risk, the uncertainty of supply and demand, blood nature as a perishable commodity, demand uniqueness. Naturally, problems in Blood Inventory Management are complex and it is not an easy task to find solutions for those problems. Unlike other supply chains, in Blood Supply Chain Management, having the right product, at the right place, in the right quantity, at the right time is a matter of life and death.

Shortages of blood products lead to high costs for society and they can cause an increase in mortality rates. Discard of blood cannot be accepted since blood donors are a scarce asset of society and donors must have recovery time between two donations, depending on the type of donation. In addition, only a small percentage (5%) of the eligible donor population donate blood (Kuruppu 2010). In the study carried out by Williamson and Devine in 2013 depict that during the next 5–10 years, blood availability in developed countries will need to increase again in order to meet the demands of the ageing population. These indicate how valuable blood is and how carefully to handle this "The Gift of Life" from the donors. Besides, blood discard rate will directly influence the attitude of people towards the blood system of the country and the first-time donor return rate (Kuruppu 2010). However, matching the supply and

demand while minimizing the shortages and wastages is a complicated task. The supply of donor blood is irregular and the demand for blood products is stochastic. Blood products are also perishable, which complicates things even further.
In inventory management of blood supply chains, assigned inventory is made up of units that are reserved for individual patients and the unassigned inventory is available for use by any patient. Once cross-matched, the units in the assigned inventory are reserved for the individual patient for between 24 hours and 72 hours ready for transfusion to avoid time-consuming cross-matching in case of urgent demand. Blood inventory management theory is a subset of the broader field of perishable inventory theory. However, due to the added complexity of the presence of both assigned and unassigned inventory, most general models from perishable inventory theory are difficult to apply or are not applicable at all (Stanger et al. 2012).

Hence, this study concentrated on analyzing and answering questions on the current state of the knowledge on this research area, gap areas of knowledge, research opportunities and future trends, and specifically attempts to answer the following questions:

RQ1: What are the major complexities in inventory management of blood supply chains?
RQ2: What are the most critical factors causing wastages and shortages of blood in blood supply chains?
RQ3: What are the most applicable methods that can be used to optimize the inventory management process of blood supply chains?

In order to answer the questions mentioned above, the researcher initiated a comprehensive examination of the existing literature on Optimization approaches for inventory management of blood supply chains before presenting the methodology and results of this study.

2. Methodology

A productive literature review has the power to lay down the foundation for advancing knowledge while unveiling the unsought research areas for future studies (Webster and Watson 2002). This indicates the importance and the potential of literature review. In order to develop a flourishing literature review, a prime important activity is the process of selecting research articles.

Firstly, articles were selected through a web search based on the keywords of the area of the study and based on the published year to be between 2000 and 2019 to ensure the relevance of the articles to the study area and novelty of findings. Keywords “inventory management,” “supply chain,” “optimization,” “simulation,” “blood,” were used.

This initial search resulted in 43 articles. In the second phase, the articles which were selected in the first phase were screened by examining the title and the abstract of the papers. This process resulted in the rejection of 17 articles. In the third phase, full scripts of the remaining articles were thoroughly examined to identify the relevance to the study area. This screening process resulted in the rejection of 7 more articles by the remaining 19 articles as the final sample for the literature review process. This Inclusion and Exclusion criteria was carried out with relevant to the above mentioned research questions and to find answers for them. The selection process is indicated in Figure 1 and the list of references include all the studied articles.

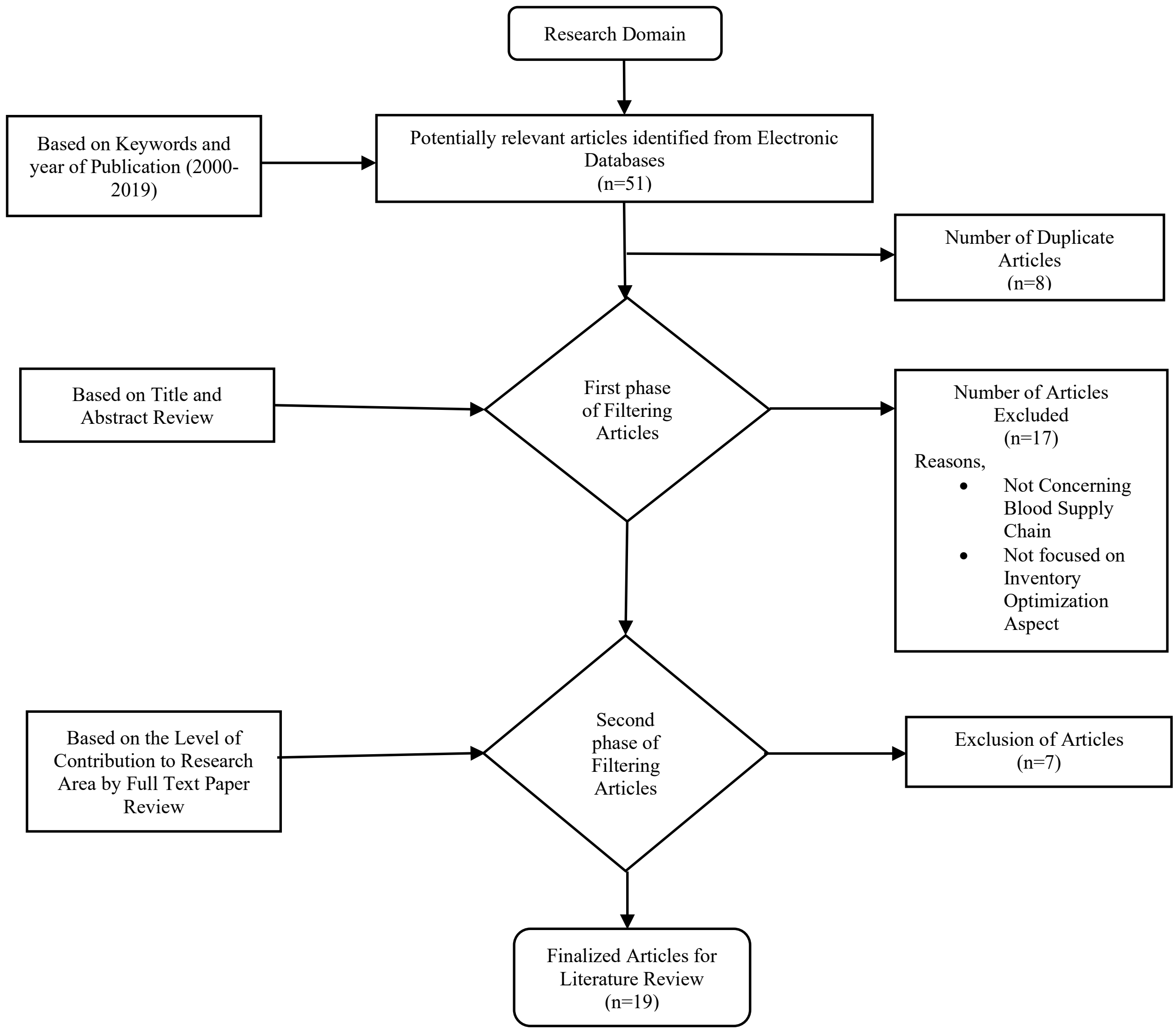

Figure 1. Screening Process

Systematic analysis of the selected pool of research papers was done to identify the optimization approaches towards Blood Inventory Management, to find out factors and complexities affecting blood inventory performance, to investigate about the gap areas in the literature, reveal future research areas and to provide recommendations for future research.

3. Content Analysis

Over the years, many researchers have contributed to the literature on optimization approaches for Blood Inventory Management. Majorly these optimization approaches were related to the Case Study approach, Operations Research, Information Systems Design & Simulation Optimization.

Research on the blood inventory management aspects has been started in the 1960s. In the 70s and 80s, many research studies have been conducted regarding blood bank management policies. Thereafter, it shows a declining trend in research work in this area. With the introduction of the lean concept, some studies were conducted to optimize blood inventory management by applying lean concepts mainly to minimize the waste of blood products (Kumari 2016).

3.1 Information System Development

Managing blood inventory creates thousands of records daily and it is so hard to stick with the manual systems and they usually lead to many errors such as data loss and duplication. By 1980s, there has been an increase of research on the development of information systems for blood inventory management process (Kumari 2016). In 2019, an information system was implemented to manage inventory levels of blood products in Brazilian Blood Banks to direct blood collection campaigns to maximize the offer and minimize the waste caused by the products' expiry dates. This system was implemented in open source development environment, without financial cost, allowing portability and gratuity characteristics for the system with real blood bank data to demonstrate system's functionalities, such as demand forecasting (Elionara et al. 2019).

3.1.1 Technology Enhancement

Implementation of electronic cross-matching has become common and is an important way to reduce unnecessary wastage of blood and to reduce lead times (Reesink et al. 2013).

3.2 Inventory Management Policies & Management Strategies

Usage of inventory procedure, "first in first out" (FIFO) policy was seen as the most important discipline in reducing wastage in blood inventory management (Stanger et. al. 2012). In order to achieve that hospitals should strictly focus on freshness, monitoring remaining shelf life and sort their inventories in the cold storage by remaining shelf-life so that the oldest units were at the front of the shelves. (Reesink et al. 2013) shows that, strategies such as implementing restocking practices of frequent small orders, rather than receiving a large stock of blood products all of a similar age is important to reduce wastages.

A study in 2012, proposes to have the transparency and visibility of Inventories for good blood inventory performance. It further suggests knowing the stock levels in all inventory locations in the hospital and the status of all RBC units. Therefore, the researcher recommends that inexperienced staff must be aware of all of the different stock locations and assigned inventories in the hospital (Stanger et al. 2012). Reesink et al (2013) also propose to consider the whole picture for the successful balance between adequate supply and minimum wastage in blood because decisions made by individual hospital blood banks ultimately affect the entire system's ability to meet demand.

3.3 Target Inventory Levels and Order Policies

To prevent a too-high stock level, it is important to prevent panic orders and Fontaine et al.(2012) propose some strategies to reduce the just-in-case ordering behavior. The study proposes to have a line of sight on all blood inventories in the hospital including other locations such as the emergency ward, and standard protocols for the appropriately experienced personnel who are making decisions about ordering in the blood bank to minimize so-called just-in-case ordering behavior.

Experience of staff plays an important role in the interpretation of demand information to make the right decision for the ordering process in blood inventory management process because different demand profiles may affect the availability of the required data (Stanger et al. 2012).

3.4 Mathematical Modeling

In summary, the research to date in blood inventory is dominated by "operations research" specialists who develop mathematical models and use them to derive policies (Van Dijk et al. 2009; Sirelson and Brodheim 1991; Cohen and

Prastacos 1981; Prastacos and Brodheim 1979; Cohen and Pierskalla 1979; Kopach et al. 2008). Integer Programming, Markov Decision Process (MDP), Dynamic programming and Two-steps stochastic programming approach are among the topmost optimization approaches used in Blood Inventory Optimization. Since the mid-1980s there has been a development of information systems to support donor screening, inventory management, blood ordering, blood usage review and compatibility testing. The constant demand is the focus of the early stage but presently, time-dependent, inventory level dependent, price-dependent, and even stochastic, demand is considered for inventory modelling (Kumari 2016).

Osorio et al. conducted a study in 2018 and built a location-allocation model to support strategic decision-making at different levels of centralization. This was done as a case study (in Colombia) to redesign the national blood supply chain under a range of realistic travel time limitations. For each scenario, an optimal supply chain configuration is obtained, together with optimal collection and production strategies. As findings, this study states that centralized systems are more efficient than decentralized systems. Total costs for the most centralized scenarios are around 40% of the costs for the least centralized scenario. The mathematical model built in this study allows decision-makers to redesign the supply network for local circumstances and determine optimal collection and production strategies that minimize total costs.

3.4.1. Demand Forecasting

Curry and Davis (2013) state that an important factor in the management of blood stocks is an accurate prediction of the demand and forecasting of blood demand tends to be based on historical patterns of use. A study in 2019 explains managing blood inventory is carried out through several stages including forecasting method, safety stock, and re-order point. As a finding, this study has obtained that exponential smoothing ($\alpha\_0.95$) to be the best forecasting method (Wce 2019). Another study conducted in 2013 explains an approach for Demand Forecasting for Blood Components of a Blood Supply Chain which can be used by blood centers during the process of estimating the quotes of blood components to deliver to hospitals and healthcare institutions. As the methodology for this, instead of adopting the traditional Moving-Average method with seven weeks' lags, a parametric model based on Box-Jenkins (BJ) procedure was proposed. This model can be used by blood bank managers to find equilibrium balance in the stock levels of blood components (Salviano 2013).

3.4.2. Dynamic & Stochastic Programming

A study was conducted on Stochastic inventory control and distribution of blood products, to optimize the blood supply chain for a single-blood center multiple-hospitals system considering products of 8 different blood types by determining the number of blood units to be processed by the blood center and the number of units of blood products to be ordered by hospitals to minimize the total cost and the shortage and wastage levels. In this study, two optimization models are formulated: A Mixed Integer Linear Programming (MILP) Model for known demands and a Stochastic Programming (SP) Model for the case where demands are uncertain, considering multiple periods, types of blood and lifetime of products. An algorithm also was developed to simulate the supply chain and evaluate the mathematical models. As a result, the Stochastic Programming (SP) Model obtained lower expected rates of shortage and wastage compared to the deterministic model (Ramírez 2017).

As cited in (Ekici et al. 2018) because of the stochastic nature of the blood supply chain, forecasts may not be reliable and accurate. Due to that researchers have developed models to handle demand uncertainty. As an example (Dijk et al. 2009) have studied the platelet production and inventory management using a combined stochastic dynamic programming and simulation model. (Haijema et al. 2009) have extended their approach to include irregular production breaks like Easter and Christmas. In studies, such (Haijema et al. 2007) authors differentiate between the demand for "old" and "young" platelets and red blood cells and develop 2-stage models to meet two different demand patterns.

3.5 Simulation Methodology

A study in 2007, describes an application of using a large-scale simulation model to improve procedures and outcomes by modelling the entire supply chain for that hospital. The author claims that model represents four advances from previous models: (1) Model an entire vertical section of the supply chain, from donor to patient; (2) Include mismatching; (3)Incorporate products with different shelf lives; (4) Include the time a unit spends in the assigned inventory stage when calculating the remaining shelf life (Katsaliaki and Brailsford 2007).

3.5.1 Discrete-Event simulation

An application of using discrete event simulation modelling to increase efficiency in blood supply chains can be seen in a study in 2006. When developing the model, the model has been refined in cooperation with medical experts as practitioners must be closely involved so that the model can be tested against their understanding as it develops. The author mentions that earlier calculations and improvement efforts of blood supply chain in focus were based on ''gut feeling' and through applying simulation to this complex system, the dynamics of the blood supply chain was more easily understood by the medical expertise (Spens and Rytila 2006).

3.5.2 Dynamic Simulation

Efficiency improvement of blood supply chain system using Taguchi method and dynamic simulation was done in a study in 2015 by applying dynamic simulation and Taguchi method to design a robust blood supply chain system to improve the blood supply chain efficiency. In Taguchi method, four main controllable factors that are arrival rate of donors, maximum inventory level, minimum inventory level and blood delivery policy and one noise factor which is demand variable have been chosen. In order to achieve a robust blood supply chain, the study proposes to have all main factors at the high level except for one factor which is the maximum inventory level (Mojib et al. 2015).

4. Descriptive Analysis

The studies on Blood Inventory Optimization are summarized in Table 1 Recently there has been an increasing trend in studies on approaches to optimization using mathematical and simulation approach.

Table 1. Framework of studies

Study	**Method**
Spens and Rytila (2006), Katsaliaki and Brailsford (2007)	Simulation Optimization
Elionara et. al. (2019)	ISD (Information System Design)
Kuruppu (2010), Stanger et al. (2012), Fontaine et al. (2012), Williamson and Devine (2013), Reesink et al. (2013), Curry and Davis (2013)	Case Study
Beliën and Forcé (2012), Mansur et al. (2018)	Literature review
Salviano (2013), Kumari (2016), Ramírez (2017), Osorio et al. (2018), Ekici et al. (2018), Wce (2019)	Mathematical Optimization
Mojib et al. (2015)	Mathematical Optimization and Simulation

4.1 Publications by Year

There had been a peak in studies towards blood inventory optimization in 2012 and 2013. After 2014 the graph confirms an increased awareness and interest amongst researchers in this area.

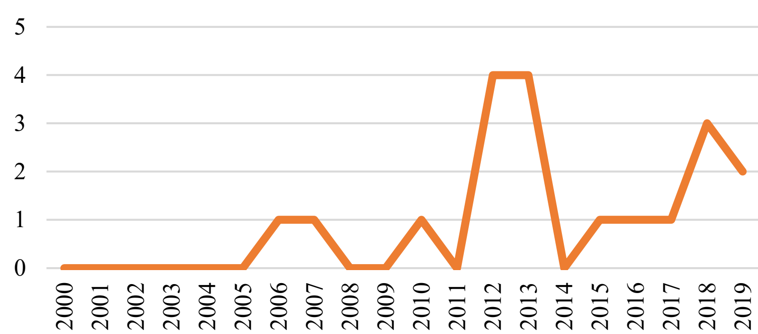

Figure 2. No. of Publications by Year

4.2 Distribution by Electronic Databases

As illustrated in Figure 3, there were six major databases identified: Emerald Insight, ResearchGate, ScienceDirect, SpringerLink, Semantic Scholar and PubMed. ResearchGate and ScienceDirect were the most prominent among them and contributed for (58%) of the reviewed papers. (53%) of the reviewed papers were from Journal Articles.

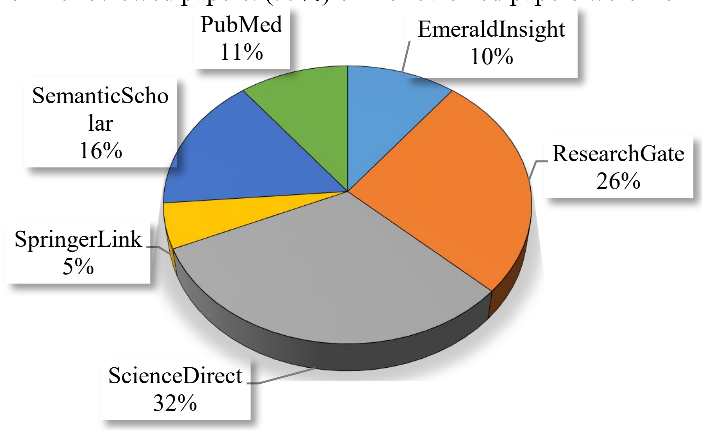

Figure 3. Electronic Database (%) for papers

4.3 Classification based on the country

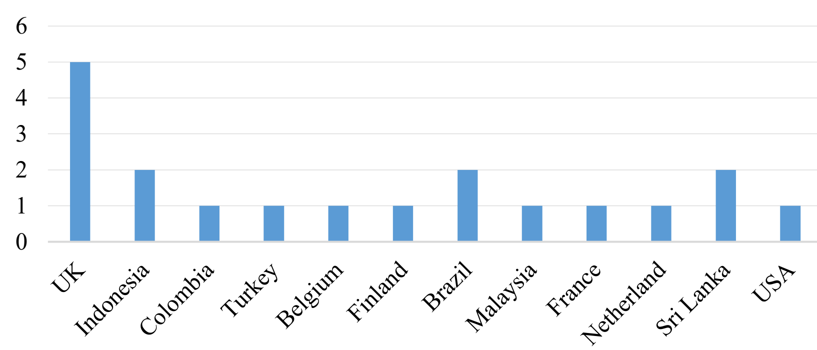

Figure 4. No. of Publications by Country

According to Figure 4, out of 19 final pool of articles UK based studies, contributes for the highest number of publications (5) towards optimizing blood inventory management.

4.4 Factors affecting Blood Inventory Performance

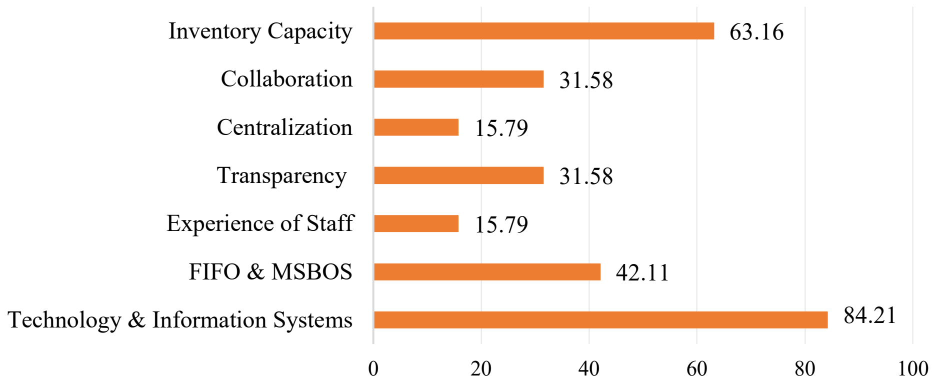

Figure 5. Factors affecting Blood Inventory Optimization (%)

As depicted by the figure above most of the studies (84%) have been concerned about the factor of Technological state and the availability of Information systems. Then they have considered Inventory Capacity and FIFO/MSBOS (Maximum Surgical Blood Ordering Schedule) respectively. Recent researches (after 2012) have been relatively more concerned on Inventory Capacity factor with the trend of approaches towards mathematical optimizations. The benefits of transparency and collaboration have shown mostly in the researches between 2010 to 2013. The literature has proved that centralized systems are relatively more efficient when managing blood inventory. Yet there is a need for further research to be carried out concerning this factor.

4.5 Complexities affecting Blood Shortages & Wastages

As figure 6 depicts; the 3 complexities that are considered highly by studies are the Uncertain Demand, Uncertain Supply and the Perishability of blood products. The added complexity of the multi-echelon system existence is lastly considered when minimizing blood shortages and wastages. The studies that were done around 2011 have more concerned about the complexities of cross-matching and the existence of assigned inventory. However, in the recent trend of mathematical optimization approaches, with the modelling limitations and complexity, the emphasis has been dropped down. Most of the studies have considered only one blood product. Modelling without these complexities makes the solution non-adaptable practically. This shows a significant vacant space for future researchers who are willing to study in this field.

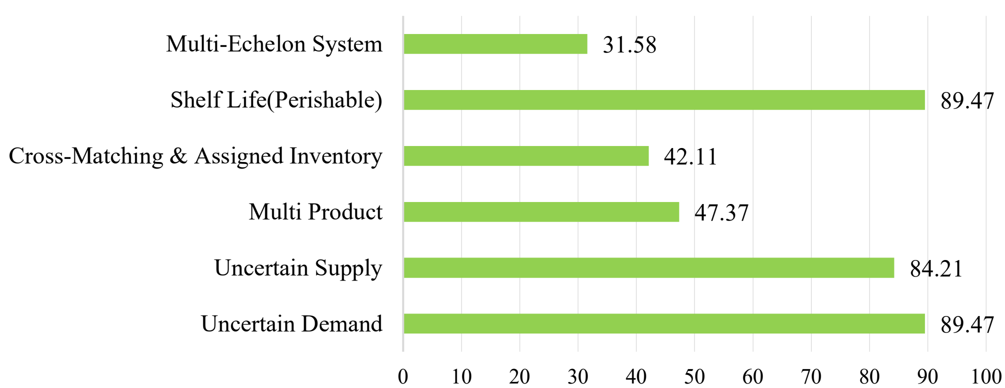

Figure 6. Complexities affecting Blood Shortages & Wastages (%)

4.6 Methodology Undertaken by Studies

The majority of studies were based on the case study approach amounting to 37%. Among them, some of them were intending to find out the best practices and policies to improve the blood inventory performance. Mathematical Optimization Approaches represent 32% by developing models for better performance. Simulation approaches took only about 11% and finally, only 5% of studies took the methodology of both mathematical optimization and simulation approach. The significance of this study is that the analysis proves only 10% of studies have taken a literature review on optimization approaches towards blood inventory management.

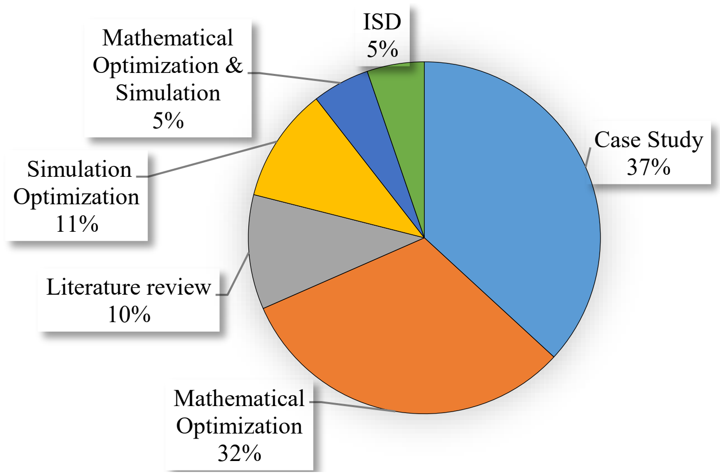

Figure 7. The methodology undertaken by studies (%)

5. Discussion & Conclusions

5.1 Gaps and Future Research Areas

Through the careful analysis of the final pool of papers for the review, the following literature gaps and potential research areas were identified.

5.1.1. Mathematical Modelling

- Use of approximation methods such as the L-Shape Method or Cutting Plane Approximation in the case of multi-stage problems, develop Heuristics, Markov processes or other solution methods to optimize the blood inventory management and supply chain (Ramírez, 2017).
- Developing an adaptive blood inventory model to support blood supply chain management that could be responsive toward demand fluctuation (Mansur et al., 2018).
- Incorporate Sensitivity analysis to the studied model to further understand the dynamics of the blood supply chain (Spens and Rytila, 2006).

5.1.2. Simulation Optimization

- Expanding the studied model to include all the hospitals served typically from an NBS Centre to identify better practices for different sized hospitals (Katsaliaki, 2007).
- Applying Simulation method to evaluate performance policy in managing blood inventory and prepare a scenario for optimizing inventory level (Wce, 2019).

5.1.3. Policies & Management Strategies

- Develop a plan for the blood service to determine whether a given scenario leads to a need for more blood, and if so, whether there is enough blood available or how much additional supply is required (Kuruppu, 2010).
- Developing blood collecting strategy to minimize shortage, outdating and incurred cost at supply chain level (Mansur et al., 2018).
- The concept of patient blood management should be further studied (Williamson and Devine, 2013).

5.1.4. Information System Design (ISD)

- Improve the planning of the inventory balance process of the blood supply chain by,
  (i) the use of neural networks with non-decimated wavelet transform to deal with irregular demands.
  (ii) the development of a tool to run in a web environment to give remote assistance to blood centers & to create a virtual network to meet the demand for blood components (Salviano, 2013).
- Build a reliable inventory management system, making it adaptive to environmental change (Mansur et al., 2018).
- Develop a system to manage inventory levels of blood products in Blood Banks to direct blood collection campaigns to maximize the offer and minimize the waste caused by expiry (Osorio et al., 2018),
- Integration of the studied model to inventory management system which is able to analyze historical demand data in order to make the forecast model independent from an analyst and transform proposed Inventory Management system into a web tool, in order to make possible registered users access the system any time, in different machines and places, via a web browser (Osorio et al., 2018).

5.1.5. Technology Enhancement

- With the recent advances such as multicomponent apheresis (MCA) initiate research on,
  (1) Increasing donor utilization
  (2) Tailoring the donations based on the demand (Ekici et al., 2018).
- Develop Cross-disciplinary systems for patient blood management to lessen the need for transfusion by early identification and reversal of anaemia with haematinics or by reversal of the underlying cause (Williamson and Devine 2013).
- Initiate integrated approaches in blood stock management between transfusion services and hospitals to minimize wastage by the use of supply chain solutions from industry (Williamson and Devine 2013).

5.2 Recommendations

Due to the complexities that exist in the blood inventory management, the solution methods undertaken also have become complex and problems arise when implementing these solutions in practical scenarios. There should be a solution, which can be more comfortably applied by medical practitioners in the daily operations in the inventory management process in blood banks. Experience of staff is a critical factor in order to improve the blood inventory performance and there should be a combined approach integrating academia and practice. In order to achieve this simulation can be used as a suitable methodology, bridging the gap between two areas.

Discrete event simulation can be used to address the problems that are arising with the stochastic nature that exist in the blood supply chain. There has been an increasing trend in mathematical optimization approaches rather the case study and other qualitative approaches in recent years. However, the final solution should be more practically adaptable and understandable by medical officers who are daily dealing with these issues. Therefore, integration of simulation approach will minimize this problem by providing more comprehensible and more efficient answers. In the simulation, optimization looks at aggregate statistics and parameters when building safety stock targets and many simulation software have the ability to generate forecast information, which is very important when predicting the demand for blood components. Simulation provides the facility for decision-makers to get relatively more aggregate and informative decisions by virtually simulating the system and identifying potential painful areas in operations. However, the implementation of a computer solution alone cannot eradicate all the bottlenecks and inefficiencies in blood inventory management. Moving towards a centralized system while empowering collaboration between blood banks will help to minimize the shortages and wastages. Continuous awareness and training should be given to the staff and inventory layout should be optimized for facilitating FIFO while increasing the transparency.

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Biographies

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Kasuni Vidanagamachchi is a Honors degree holder in Transport and Logistics Management from University of Moratuwa, Faculty of Engineering, and holds a Masters degree from Business Administration (MBA) in Postgraduate of Institute of Management, University of Sri Jayewardenepura. She is also a Member of the Institute of Logistics and Transport (MILT), UK. Ms. Vidanagamachchi has industrial experience as a Logistics Analyst for Advantis 3PL Plus, a subsidiary of Hayleys Group, a leading Third Party Logistics Services Provider in Sri Lanka for over a period of four years, where she obtained the exposure to the supply chain and logistics practices of some of the key multinational companies in Sri Lanka.

L.D.J.F. Nanayakkara is a Senior Lecturer who served for 42 years at the Universities of Kelaniya and Moratuwa in Sri Lanka and for a short period at the Sheffield Hallam University in the UK. He obtained B.Sc. Eng. (Hon) degree in the field of Mechanical Engineering from the University of Moratuwa, Sri Lanka in 1974 and his Ph.D. in the area of Production Management and Manufacturing Technology from the University of Strathclyde, U.K. in 1983. He works as a lecturer, researcher, trainer and consultant to the industry and Universities. He has published research papers in many refereed journals and conference proceedings in the areas of Production Operations management, Industrial Engineering and Industrial Management. He has been engaged in the development and delivery of related curricula at undergraduate, postgraduate, vocational and school level education in the subject areas of Industrial Engineering, Supply Chain Management, Business Process Management and Production Technology.