Taylor & Francis
Taylor & Francis Group

International Journal of Management Science and Engineering Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tmse20

A resilient approach to modelling the supply and demand of platelets in the United Kingdom blood supply chain

O.A Ejohwomu, J Too & D.J Edwards

To cite this article: O.A Ejohwomu, J Too & D.J Edwards (2021) A resilient approach to modelling the supply and demand of platelets in the United Kingdom blood supply chain, International Journal of Management Science and Engineering Management, 16:2, 143-150, DOI: 10.1080/17509653.2021.1892548

To link to this article: https://doi.org/10.1080/17509653.2021.1892548

INTERNATIONAL JOURNAL OF MANAGEMENT SCIENCE AND ENGINEERING MANAGEMENT
2021, VOL. 16, NO. 2, 143–150
https://doi.org/10.1080/17509653.2021.1892548

A resilient approach to modelling the supply and demand of platelets in the United Kingdom blood supply chain

O.A Ejohwomu [a], J Too [a] and D.J Edwards [b]

[a]Department of Mechanical, Aerospace and Civil Engineering, University of Manchester, Manchester, UK; [b]Plant and Machinery Management, Faculty of Technology Environment and Engineering, Birmingham City University, Birmingham, UK

ABSTRACT

The short shelf-life of platelets together with their stochastic demand and variable supply create problematic decision making for inventory managers who seek to maintain optimal stock levels. This paper develops a novel simulation model that acts as a decision support tool for identifying optimal stock levels to guarantee the availability of stock and, eliminate wastage and outages within the platelet supply chain. A multi-method approach is delineated upon that combines agent-based and discrete event modelling built on Anylogic software using data collected from typical UK Stock Holding Units (SHUs). The model simulates the demand and supply of 24 different platelet types and recommends the appropriate stock level at SHUs. Adopting these stock levels guarantees stock availability and improves performance at the SHU by reducing wastage by 78%. This research not only represents the first attempt to fully understand the UK platelet supply chain but also presents an advanced simulation model that adopts a 'pull' system of platelet inventory management. Further, the concept of resilience is integrated into the design of the solution methodology by testing the model's behaviour on unexpected disruptions in the supply chain.

ARTICLE HISTORY
Received 14 June 2020
Accepted 16 February 2021

KEYWORDS
Blood supply chain; platelets; simulation; inventory management; optimisation

JEL classification
C61

1.0. Introduction

The supply of blood products is irregular (due to donor uncertainties) and its demand stochastic (Beliën & Forcé, 2012) making it difficult to accurately forecast production and schedule blood donations (Samani, Hosseini-Motlagh, & Homaei, 2020). Therefore, inventory management seeks a trade-off between shortages and wastage to guarantee the availability of blood products while simultaneously minimizing expiries (Stanger, Yates, Wilding, & Cotton, 2012). Although over a hundred different products can be extracted from blood, platelets, red blood cells and plasma are the most important components (Katsaliaki & Brailsford, 2007). Platelets are particularly significant because they have multiple uses in chemotherapy, bone marrow transplants, treatment of coronary artery diseases and more recently, in the development of the Coronavirus (COVID-19) vaccine (Chang, Yan, & Wang, 2020).

One challenge for inventory managers however, is that platelets have the highest rate of perishability- with a five to seven days storage shelf-life (Zahiri, Torabi, Mohammadi, & Aghabegloo, 2018). Indeed, in the USA and Western Europe, approximately 20% of platelets collected result in expiries (Rajendran & Ravindran, 2020). Apart from wastage, unpredictable challenges caused by unplanned surgeries, natural disasters, equipment breakdown, war and labour strikes lead to significant disruptions and losses within the blood supply chain and consequently, unsatisfied demands (Haeri, Hosseini-Motlagh, Samani, & Rezaei, 2020). Therefore, it is crucial to preserving public health, that policies are adopted that assimilate the concept of 'resilience' (i.e. an innate ability to withstand large-scale disruptions) into planning and inventory management to remain reliable despite unexpected challenges (Rajendran & Srinivas, 2020).

To resolve this problematic public health conundrum and achieve equilibrium between blood products supply and demand, this study focuses on platelet inventory management and seeks to answer the following inductive questions: 1) What is the optimal level of platelet inventory that will meet demand and reduce shortages? 2) What is the impact of relying on hospital demand to make decisions on inventory levels at Stock Holding Units (SHUs) vis-à-vis depending on the supply side? 3) How can resilient inventory management decisions be made in the face of an emergency?

Although several authors have attempted to provide a solution to the platelet inventory management problem, Beliën and Forcé (2012) report upon a discernable lack of fully scalable models (both mathematical and simulation) that provide clear demonstrable evidence of performance improvement in practice. Most innovative academic solutions are limited to theoretical contexts only (Stanger et al., 2012) and research into blood inventory management remains scant (Rajendran & Srinivas, 2020). Within the specific area of platelet inventory management research, consideration of the different platelet categories, together with their ABO and rhesus groupings remains unexplored. Studies predominantly devote their analysis to one type of platelet product (Haeri et al., 2020), which is mostly apheresis platelets. Furthermore, integrating the concept of resilience into the design of a solution methodology for platelet inventory management has not yet been fully addressed. Haeri et al. (2020) conducted perhaps the closest match to this present study and considered different resiliency

CONTACT O.A Ejohwomu ✉ obuks.ejohwomu@manchester.ac.uk Department of Mechanical, Aerospace and Civil Engineering (MACE), Pariser Building Room E22, Sackville Street, Manchester M13 9PL, UK

measures in the blood supply chain. However, their study *(ibid)* focuses on the design of the blood supply chain network. Consequently, this current research utilizes data collected from a real-life SHU in England to develop a pragmatic decision support tool that can be implemented to generate optimal stock levels. In addition to being the first attempt to fully understand the UK platelet supply chain, this novel study is also the first to propose a multi-product simulation model that advances previous simulation models viz.: 1) it analyses 24 different types of platelet categories broken down into the type of platelet unit (i.e. apheresis, pooled and paediatric), their different ABO categories and their rhesus groupings; 2) the simulation model is designed to operate based on a 'pull' system meaning that the SHU's stock levels are influenced by hospital demands. Given that the system operates in a stochastic environment, efficient production planning is critical in reducing wastage (Hu, Ramaraj, & Hu, 2020). The proposed 'pull' system therefore facilitates the elimination of wastage and reduction of cost (Zheng & Lu, 2009) since the model outputs inform production planning; 3) substitution of platelet products is considered for optimal inventory management; 4) The model's resilience was tested in an emergency case study of a real-life SHU.

The rest of the paper is organised as follows: *section 2* synthesises relevant literature on platelet supply chain; *section 3* presents the case study; *section 4* delineates the methodology adopted; *section 5* presents the study's results and managerial insights inferred from these, and *section 6* provides conclusions and signposts future opportunities for further research.

2.0. The platelet supply chain: a literature review

Extant literature reviewed on platelet supply chain optimisation illustrates that international studies have critically evaluated platelet inventory management optimisation approaches from various context-specific perspectives. Although early studies extend back to the 1960s (Cohen & Pierskalla, 1979; Osorio, Brailsford, & Smith, 2015), the platelet supply chain has hitherto received scant academic attention until recent years (Blake, 2017).

Several stochastic approaches such as probabilistic dynamic programming, fuzzy programming and robust optimisation are key in developing optimised solutions under uncertain conditions (Isaloo & Paydar, 2020). For instance, Haijema, Van Dijk, Van Der Wal, and Sibinga (2009) adopted Stochastic Dynamic Programming (SDP) with simulation to arrive at policies that they claim would lead to shortage levels of less than 1% and reduce wastage from 20% to 1% during Christmas, New Year's and Easter breaks. Due to the short shelf-life of platelets, these breaks may seriously affect the levels of shortages and wastage; making their findings particularly noteworthy. Van Dijk, Haijema, Van Der Wal, and Sibinga (2009) ignored the stock age distribution and combined SDP with discrete event modelling to arrive at an 'order-up-to' rule for each day of the week. The major limitation of this study (*ibid*) however, was their oversight in the presentation of results. Blake (2009) points out this error and strongly contests the results of Van Dijk et al. (2009), arguing that ignoring the age-distribution of stock yields inventory levels is not practical. Further, Abdulwahab and Wahab (2014) analyzed the performance of the Canadian Blood Service and proposed a mathematical model based on approximate dynamic programming. The model examined different supply policies (circular, first-in-first-out (FIFO) and last-in-first-out (LIFO)), concluding that increasing the order delivery to two times per day and incorporating a strict FIFO policy produces minimal inventory shortages, minimum outdates and minimum average inventory. Katsaliaki and Brailsford (2007) adopted a different approach and utilised discrete-event simulation. They (*ibid*), concluded that strict adherence to FIFO inventory policy and the introduction of two routine deliveries to hospitals (vis-a-vis one), would improve system performance, arriving at the same conclusion as Abdulwahab and Wahab (2014).

The World Health Organization (2011) guidelines recommend that adequate contingency plans should be implemented by blood centres for collection, processing and use of blood products during a pandemic. Rajendran and Srinivas (2020), consider the effects of disruption on the supply chain and adopt mathematical modelling to develop inventory management policies that offer a trade-off between wastage and shortages. Haghjoo, Tavakkoli-Moghaddam, Shahmoradi-Moghadam, and Rahimi (2020); Hosseini-Motlagh et al. (2020); Hamdan and Diabat (2020) and Yaghoubi, Hosseini-Motlagh, Cheraghi, and Gilani Larimi (2020) made further contributions in developing solutions for optimising the supply chain under disruptions to minimize transportation, inventory and fixed costs as well as lower the rate of shortages and wastage.

3.0. Case study description

The National Health Services Blood and Transplant (NHSBT) is mandated to ensure blood products are delivered to UK hospitals in a timely and sufficient manner. Approximately 28,000 units of blood and its components are collected weekly from fixed and mobile donation centres. The collected blood is then tested for ABO, rhesus grouping, infectious agents and viruses, and then processed in manufacturing centres (Baesler, Nemeth, Martínez, & Bastías, 2014). The UK's three manufacturing centres (located in Manchester, Colindale and Bristol) centrifuge whole blood into the three major components: plasma, platelets and red blood cells. After processing, the blood components are stored in SHUs ready for issue when ordered by transfusion laboratory managers. The current approach for inventory management in the SHUs is to hold fixed stock targets that are reviewed every six months. This simplistic approach to platelet inventory management tends to be time-consuming and makes it difficult to make production decisions that will result in optimal inventory levels. Efficient and effective supply chains ensure that products are delivered in the right quantities and at the right time and place (Puška, Kozarević, & Okičić, 2020). Since evidence-based inventory management leads to best practice in blood services, this study adopted an SHU as a case study to illustrate the developed simulation model's applicability and its solution approach for effective platelet inventory management.

4.0. Materials and methods

A mixed philosophical stance was adopted using interpretivism to analyse existing literature and justify the novelty of

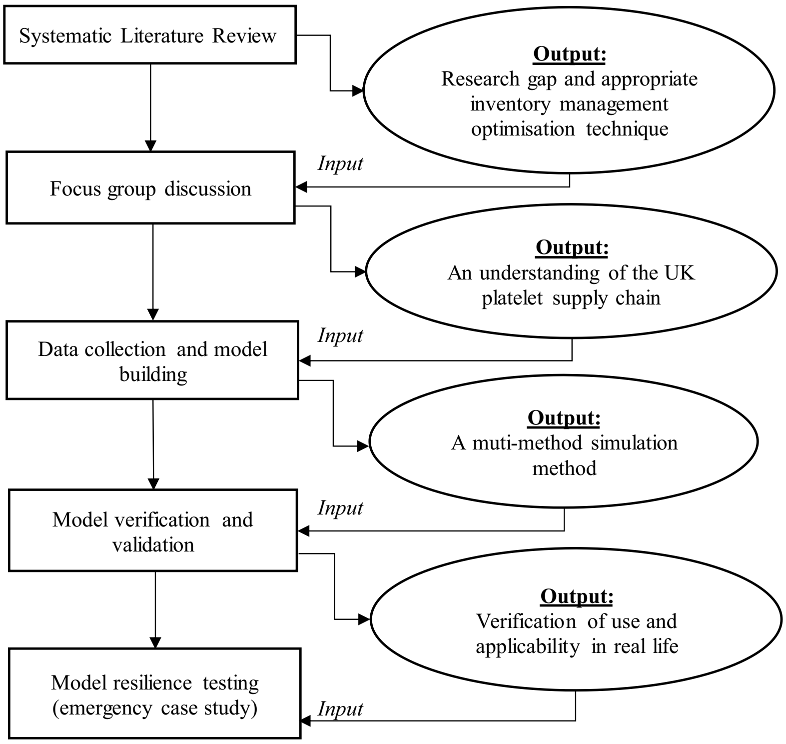

Figure 1 Overview of the research process.

this present study (Chamberlain, Edwards, Lai, & Thwala, 2019; Edwards, Pärn, Love, & El-Gohary, 2017; Roberts, Pärn, Edwards, & Aigbavboa, 2018), and positivism (Edwards et al., 2020; Kulkarni et al., 2018) to develop the simulation model. Within this overarching epistemology, a mixed-method approach was adopted, incorporating both qualitative and quantitative techniques to comprehensively model the case study. This approach was implemented in five interrelated stages; specifically, the output of one stage iteratively informing the next as illustrated in (Figure 1) below.

4.1. Focus group discussions

In this multi-level single case study, a non-probability sampling technique was used to constitute a focus group. The formation of the group, discussions and site visits to two of the three manufacturing sites occurred over twenty months. This extended period was needed to negotiate research support but also secure a more comprehensive understanding of the SHU's operational activities. This practical knowledge accrued was instrumental in developing the simulation model that accurately reflected reality. Focus group discussions were chosen because unlike interviews, they provide a more precise and clearly defined focus on the topic, enabling an interactive discussion between the participants (Pärn & Edwards, 2017). The focus group participants consisted of six senior staff members of NHSBT who are responsible for making decisions on the stock levels within the UK blood supply chain and had between 5 and 30-years' experience in blood manufacturing. Although a sample frame of ten staff was originally identified, only six responded positively thus representing a 60% response rate. Semi-structured questions were used to guide interactions, and the ensuing discourse recorded, transcribed and analysed using NVivo.

4.2. Developing the simulation model

Agent-based modelling was combined with discrete event modelling to develop the simulation model. Due to the complexity of the platelet supply chain, system behaviour cannot be accurately defined (Osorio et al., 2015). However, the key variables and dependencies within the system can be identified. Agent-based modelling was chosen since it allows the system's 'global' behaviour to be understood by merging individual behaviours (Grigoryev, 2018). The variable 'hospital demand' was taken as an agent interconnected with another agent; the 'SHU' and the activities within the SHU (such as 'replenishment orders', 'shortages' and 'wastage') were modelled using a discrete-event to show how they interact within the system. The model was developed on Anylogic software together with a Java code written to replicate the daily transaction activities at the SHU. Overall, the simulation model considers a 'pull' system where the stock levels are influenced by hospital demand (refer to Figure 2), eliminating the need to 'push' blood products to the hospitals. It evaluates the appropriate stock levels for the 24 different platelet products through what-if analysis (Terzi & Cavalieri, 2004).

4.2.1. Data required by the model

Data on hospital demands for the 24 different platelet categories by platelet type, quantity and blood group were obtained for the period between April 2017 and June 2019. Historical data was collected over two years to cover any seasonality that brings about variation in demand thus, presenting an accurate temporary picture of the platelet supply chain. A source of uncertainty in this model (as replicated in a real system) is hospital demand for platelet units. Therefore, to incorporate variability in this demand, normal probability distributions at 95% confidence level were fitted

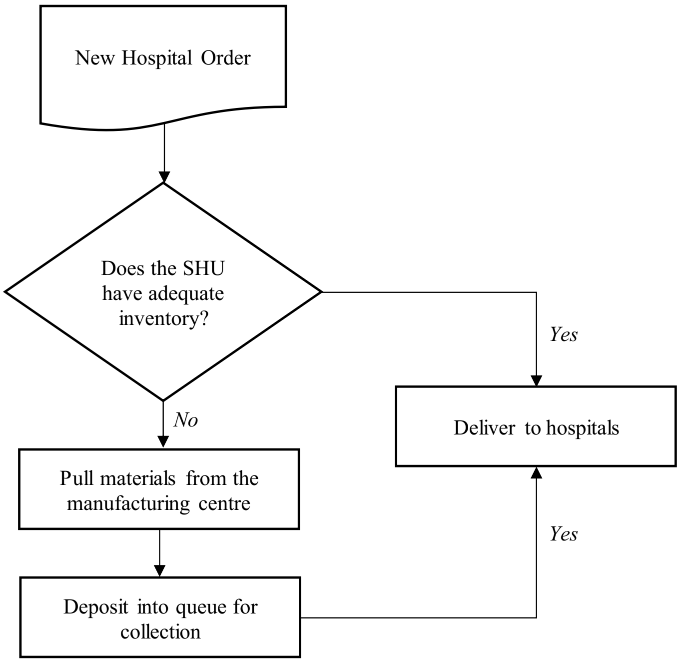

Figure 2. Model pull logic.

to historical hospital demand data and analysed as the model's input parameters.

4.2.2. Model assumptions

The simulation was developed based on the following model assumptions viz: 1) because platelet shelf-life is seven days (Blake, 2017; Zahiri et al., 2018), the model assumes a shelf-life of four days because processing at the manufacturing centre before the product arrives at the SHU takes up to three days; 2) the SHU strictly adheres to a FIFO ordering policy; 3) the SHU has enough staff and equipment to operate at increased capacity; and 4) because the model scope does not extend to the manufacturing and donation centres, it is assumed that there is enough platelet supply to replenish the SHU's orders and the lead time is two days.

4.2.3. Model behaviour

The inventory levels of the 24 platelet types were modelled based on a continuous inventory review system; accounting for fluctuations in stock according to hospital demand and replenishment orders from the manufacturing centre (refer to Figure 3). Given the critical importance of having some blood products available (at all times) in the SHU, minimal safety stock and dynamic re-order points were defined for each platelet product at a 95% service level. Stock received from the manufacturing centre is stored in FIFO order at the SHU.

Ideally, a hospital should be supplied with the same blood group of platelets that they have ordered from the SHU but this is not always possible due to product unavailability. Therefore, to manage the supply and demand, NHSBT may (in certain situations) request hospitals to accept a different ABO group from what was ordered. A Negative platelets for instance are the universal platelet type and are provided as a substitute for hospital demands. Each hospital request is first matched with the available SHU stock and the model allows for substitution for A Negative platelets if the same group demanded is unavailable at the time of the request. To reinforce this point, Participant A said:

> "In basic what I am doing all the time is making more of the more valuable units. Like all the ones that are A Neg, I am just always making more . . . I am doing a lot of substitution to push all the products out . . . "

The model runs for a year, which is considered sufficient to capture variability in the processes at the SHU – taking into consideration that one complete cycle of a platelet unit is only seven days.

4.3. Model verification and validation

The model was developed over four iterations based on feedback from professional practitioners in the UK blood supply chain. It was first built based on the authors' understanding of the platelet supply chain and thereafter, modified to include ageing of the platelet units over four days, A Negative platelet substitution and incorporating a dynamic re-order point for each of the products. The model was verified as a true representation of the SHU's daily transactions and its assumptions also viewed to be reasonable and realistic – as indicated by participant E viz:

4,4. "The assumptions are sensible for the SHUs."

The model was populated with data from the SHU's operations in 2019 and was validated for reasonableness of its outputs by running the simulation 100 times. Harrell, Bateman, and Gogg (1995) highlight that this number of replications is ideal for ascertaining model output accuracy. The validation results showed no significant difference in the operational inventory and wastage levels (refer to Table 1).

5.0. Results

The daily inventory levels derived from the simulation were compared to the actual target stock held at the SHU for July 2019 (specifically 1st July to 28 July 2019) and the variance determined as overstocked units. Due to the platelets' short shelf-life, this study describes an overstocked unit

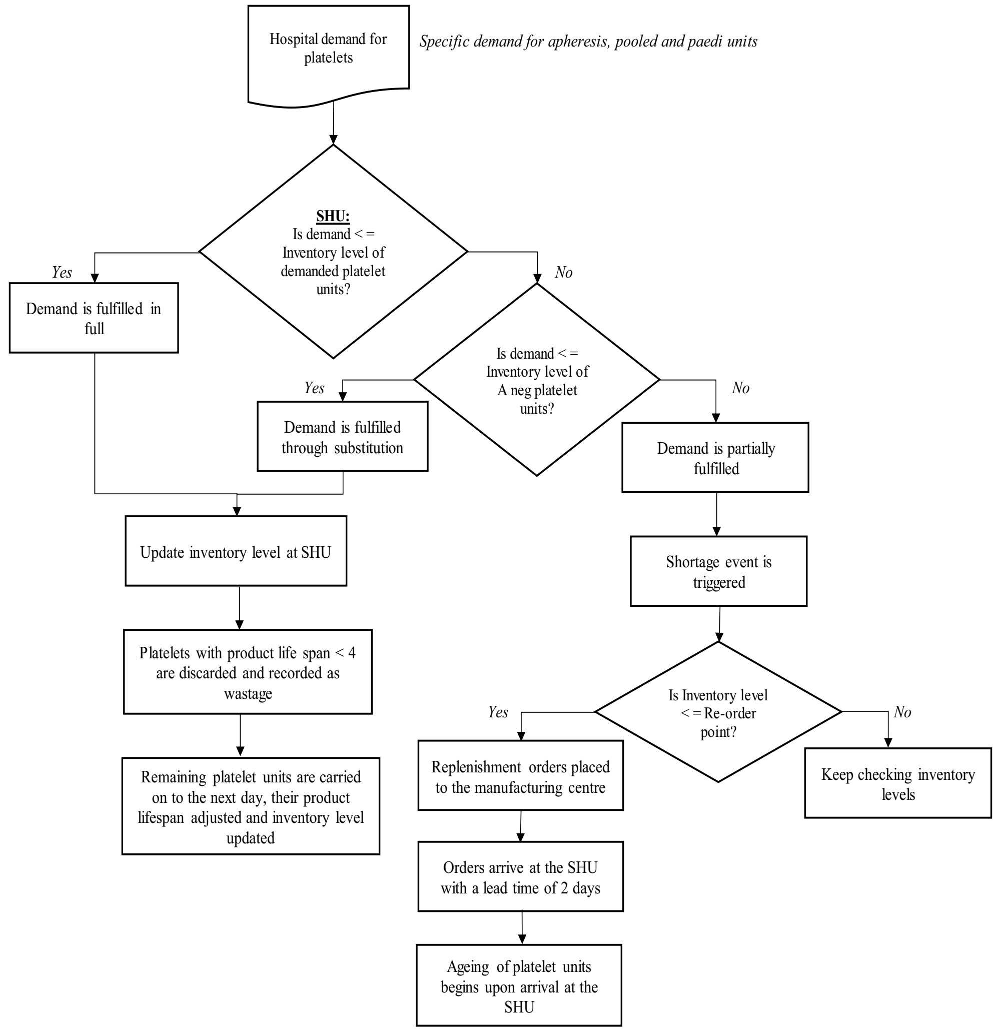

Figure 3. Model behaviour flowchart.

as any surplus platelet unit held within the SHU that is nearing expiry as confirmed by participant A, viz:

> I mean if a platelet is near day 7, it is an overstock as I am very unlikely to use it, I'm pretty sure I'm gonna expire it, I have zero probability to use it

Since the level of inventory held at the SHU influences expiries and outages, it constituted the model's key performance indicator (KPI).

5.1. Inventory levels

Average daily inventory levels for the different platelet products were simulated based on hospital demand variations and the results determined over five iterations to capture input variability. Simulated results were then analysed in comparison to the target inventory levels held in the SHU between 1 July 2019 and 28 July 2019. Although inventory holding costs are not considered in this model, holding higher inventory than necessary would certainly result in higher operational costs and subsequently, increased wastage and shortages. The results illustrate a 14% overstock of apheresis platelets and pooled platelets, and an 82% understock of paedi platelets (refer to Table 2).

Due to the uncertainty in hospital demand for the products and their lifesaving property, the SHU holds excess inventory, especially for apheresis platelets, leading to wastage. Results indicate that by using a 'pull' system where hospital demand influences the SHU's inventory levels, SHU performance is improved by reducing wastage by 78% and leading to financial savings.

Table 1. Model validation- comparison of actual data to simulation results.

Apheresis platelets						
	Actual		Simulated		Variances	
Blood type	Inventory level	Wastages	Inventory level	Wastages	Inventory level	Wastages
A-	14	5	13	3	1	2
A+	35	14	34	12	1	2
AB-	1	0	1	0	0	0
AB+	3	1	3	0	0	1
B-	2	1	1	0	1	1
B+	10	5	9	5	1	0
O-	5	2	7	1	2	1
O+	26	10	27	9	1	1

Table 2. Simulation results for daily inventory level**s**.

Blood type	Apheresis			Pooled			Paedi		
	Model results	Actual target	% over/under stock	Model results	Actual target	%over/under stock	Model results	Actual target	%over/under stock
A-	12	14	14% overstock	7	12	42% overstock	5	1	400% understock
A+	34	35	3% overstock	33	30	10% understock	1	4	75% overstock
AB-	–	1	100% overstock	–	1	100% overstock	0	1	100% overstock
AB+	3	3	0%	1	2	50% overstock	0	1	100% overstock
B-	1	2	50% overstock	1	2	50% overstock	0	1	100% overstock
B+	8	10	20% overstock	11	9	22% understock	6	1	500% understock
O-	9	5	80% understock	7	4	75% understock	3	1	200% understock
O+	28	26	8% understock	27	22	23% understock	1	3	67% overstock

Table 3. Analysis of SHU outdated (expired) units.

Blood type	Apheresis			Pooled			Paedi		
	Actual units	Simulated units	% improvement	Actual units	Simulated units	% improvement	Actual units	Simulated units	% improvement
A-	5	0	100%	6	–	100%	5	0	100%
A+	14	4	71%	16	4	75%	13	0	100%
AB-	0	0	0%	0	0	0%	0	0	0%
AB+	1	0	100%	1	–	100%	2	0	100%
B-	1	0	100%	1	–	100%	1	0	100%
B+	5	1	78%	5	1	81%	6	1	83%
O-	2	1	56%	3	–	100%	3	0	100%
O+	10	4	61%	12	3	75%	14	0	100%

For instance, considering the cost implications of outdated A Negative apheresis platelets, the authors determine that the organisation loses approximately £169,915 from this one product since apheresis platelets are sold to hospitals at £232.76.

5.2. Outdated units

The number of outdated units is an important KPI for blood supply chains. Since blood centres face the challenge of meeting demand without overstocking – the strategy adopted involves pushing platelets out of their system to avoid internal wastage. This is implemented by moving platelets to hospitals before they expire rather than awaiting hospital orders. Although this reduces internal wastage, it does not provide a solution to the systemic problem since wastage are only transferred to another part of the supply chain and not eliminated. This common practice was explicitly stated by Participant B who said:

> When there is something that's coming to end of shelf-life, they'll push it into that local hospital.

While overstocking may be a safety measure, wastage of units not only affects the SHU's operational costs but is also a waste on the donor's time and effort (Stanger et al., 2012). The SHU's wastage levels (when inventory is held at the units, as presented in Table 2) were analysed in comparison to the actual monthly expiries at the SHU (refer to Table 3). Baesler et al. (2014) maintains that an acceptable inventory policy is one that maximizes demand satisfaction while minimizing waste levels. Adopting the 'pull' system in determining the inventory level (as opposed to utilizing fixed targets as is the current case) significantly reduces the overall level of expiries from 16.63% to 3% while guaranteeing the availability of stock when hospitals demand.

5.3. Shortages

Shortages are not experienced when executing the model because it assumes that as soon as a replenishment order is made at the SHU, the order requests will be fulfilled by the manufacturing centre within 48 hours. In reality, this may not be possible because the collection side of the supply chain affects the availability of products at the manufacturing centre. However, considering a reasonable lead time of 48 hours and implementing the 'pull' system the shortages are reduced from 5% to 0%.

5.4. Model resilience

The model must be resilient to unexpected challenges and disruptions in the supply chain (Sterbenz et al., 2010) (such as equipment breakdown and natural disasters). Thus, resilience measures in the optimisation of inventory were taken into consideration to guarantee that hospital demand for platelet products would be met in periods of unexpected changes. The simulation model's resilience, in this case, was tested in the event of an emergency. The average hospital demands were multiplied by a factor of 10 to determine the behaviour of the model under extreme conditions. The simulation running in virtual time mode took 3 hours 24 minutes compared to the normal conditions that took 15 minutes. The simulation's results were compared to the baseline scenario and revealed an appropriate increase in stock levels as expected and reasonable wastage. For instance, the inventory level for A Negative apheresis platelets increased to 117 units from 12 units when the demand increased from 4 to 40 units. Conversely, wastage was maintained at 0 units indicating the sensitivity of the model to computing wastage relative to the product life span when there is a surge in demand.

6.0. Conclusion

Besides providing an innovative tool for inventory management at NHSBT, this study represents the first attempt to fully understand the UK platelet supply chain. A multi-method simulation model was developed to capture the activities of a real-life SHU, verified and validated by experts in the UK platelet supply chain. The performance of the SHU can be improved by keeping the daily inventory levels as (12A-, 34A+, 0AB-, 3AB+, 1B-, 8B+, 9O-, 28O+) for apheresis platelets, (7A-, 33A+, 0AB-, 1AB+, 1B-, 11B+, 7O-, 27O +) for pooled platelets and (5A-, 1A+, 0AB-, 0AB+, 0B-, 6B+, 3O-, 1O+) for paediatric platelets while strictly adhering to the FIFO policy. This paper's outcomes provide insight into the trade-off between shortages and expiry rates, and can assist decision-makers in production planning for optimised inventory management and subsequently, efficient use of resources (Hu et al., 2020). Additionally, incorporating measures of resilience into decision making guarantees the availability of platelet products under peculiar circumstances.

A major limitation of this study is that the analysis did not include operational costs. Further, while the model represents the SHU operating independently from the activities at the manufacturing centre and collection points, in real life, the decisions made in other parts of the supply chain may significantly affect the activities at the SHU. Future research could extend this model to incorporate the activities of the other parts of the supply chain to provide a robust solution to the platelet problem experienced. In particular, incorporating variability in supply may provide a better picture of shortages as a result of variable lead times. Future research could also incorporate stock holding costs in determining the optimal stock levels to illustrate the potential savings from the implementation of the optimal stock levels.

Acknowledgments

We express our gratitude to Professor Mike Murphy, Laura Hontoria Del Hoyo, Helen Livingstone, Jackie Morgan, Dr Clement Okiemute Ejohwomu, Dr Aloaye Foy-Yamah and Dr Venu Kollipara for their continuous support in providing data and enlightening information on the blood supply chain within the United Kingdom. Without their time and support, this project would not have been possible.

Disclosure statement

The authors hold no conflict of interest with the publication of the results included in this paper.

ORCID

O.A Ejohwomu http://orcid.org/0000-0001-7098-8999

References

Abdulwahab, U., & Wahab, M. I. M. (2014). Approximate dynamic programming modeling for a typical blood platelet bank. *Computers & Industrial Engineering*, *78*, 259–270.

Baesler, F., Nemeth, M., Martínez, C., & Bastías, A. (2014). Analysis of inventory strategies for blood components in a regional blood center using process simulation. *Transfusion*, *54*(2), 323–330.

Beliën, J., & Forcé, H. (2012). Supply chain management of blood products: A literature review. *European Journal of Operational Research*, *217*(1), 1–16.

Blake, J. T. (2009). On the use of operational research for managing platelet inventory and ordering. *Transfusion*, *49*(3), 396–401.

Blake, J. T. (2017). Determining the inventory impact of extended-shelf-life platelets with a network simulation model. *Transfusion*, *57*(December), 3001–3008.

Chamberlain, D., Edwards, D. J., Lai, J., & Thwala, W. D. (2019). Mega event management of formula one grand prix: An analysis of literature. *Facilities*, *37*(13/14), 1166–1184.

Chang, L., Yan, Y., & Wang, L. (2020). Coronavirus disease 2019: Coronaviruses and blood safety. *Transfusion Medicine Reviews*, *34* (2), 75–80.

Cohen, M. A., & Pierskalla, W. P. (1979). Target inventory levels for a hospital blood bank or a decentralized regional blood banking system. *Transfusion*, *19*(4), 444–454.

Edwards, D. J., Pärn, E. A., Love, P. E. D., & El-Gohary, H. (2017). Machinery, manumission and economic machinations. *Journal of Business Research*, *70*, 391–394.

Edwards, D. J., Rillie, I., Chileshe, N., Lai, J., Hosseini, M. R., & Thwala, W. D. (2020). A field survey of hand–arm vibration exposure in the UK utilities sector. *Engineering, Construction and Architectural Management*, *27*(9), 2179–2198.

Grigoryev, I. (2018). Anylogic in three days: A quick course in simulation modeling. [Online]. Retrieved from: https://www.anylogic.com/resources/books/free-simulation-book-and-modeling-tutorials/

Haeri, A., Hosseini-Motlagh, S. M., Samani, G. M. R., & Rezaei, M. (2020). A mixed resilient-efficient approach toward blood supply chain network design. *International Transactions in Operational Research*, *27*(4), 1962–2001.

Haghjoo, N., Tavakkoli-Moghaddam, R., Shahmoradi-Moghadam, H., & Rahimi, Y. (2020). Reliable blood supply chain network design with facility disruption: A real-world application. *Engineering Applications of Artificial Intelligence*, *90*(1–18), 103493. 2020.

Haijema, R., Van Dijk, N., Van der Wal, J., & Sibinga, S. C. (2009). Blood platelet production with breaks: Optimization by SDP and simulation. *International Journal of Production Economics*, *121*(2), 464–473.

Hamdan, B., & Diabat, A. (2020). Robust design of blood supply chains under risk of disruptions using Lagrangian relaxation. *Transportation Research Part E: Logistics and Transportation Review*, *134*(1–18), 101764. 2020.

Harrell, C. R., Bateman, R. E., & Gogg, T. J. (1995). *System improvement using simulation* (3rd ed.). Orem (UT): PROMODEL® Corporation.

Hosseini-Motlagh, S. M., Samani, M. R. G., & Homaei, S. (2020). Blood supply chain management: robust optimization, disruption risk, and blood group compatibility (a real-life case). *Journal of Ambient Intelligence and Humanized Computing, 11* (3), 1085–1104

Hu, Z., Ramaraj, G., & Hu, G. (2020). Production planning with a two-stage stochastic programming model in a kitting facility under demand and yield uncertainties. *International Journal of Management Science and Engineering Management*, *15*(3), 237–246.

Isaloo, F., & Paydar, M. M. (2020). Optimizing a robust bi-objective supply chain network considering environmental aspects: A case study in plastic injection industry. *International Journal of Management Science and Engineering Management*, *15*(1), 26–38.

Katsaliaki, K., & Brailsford, S. C. (2007). Using simulation to improve the blood supply chain. *Journal of the Operational Research Society*, *58*(2), 219–227.

Kulkarni, S. S., Edwards, D. J., Chapman, C., Pärn, E. A., Cornish, R., & Aigbavboa, C. (2018). Evaluation of vehicle lightweighting to reduce greenhouse gas emissions with focus on magnesium substitution. *Journal of Engineering, Design and Technology*, *16*(6), 869–888.

Osorio, A. F., Brailsford, S. C., & Smith, H. K. (2015). A structured review of quantitative models in the blood supply chain: A taxonomic framework for decision-making. *International Journal of Production Research*, *53*(24), 7191–7212.

Pärn, E. A., & Edwards, D. J. (2017). Conceptualising the FINDD API plug-in: A study of BIM-FM integration. *Automation in Construction*, *80*, 11–21.

Puška, A., Kozarević, S., & Okičić, J. (2020). Investigating and analyzing the supply chain practices and performance in agro-food industry. *International Journal of Management Science and Engineering Management*, *15*(1), 9–16.

Rajendran, S., & Ravindran, R. A. (2020). Multi-criteria approach for platelet inventory management in hospitals. *International Journal of Operational Research*, *38*(1), 49–69.

Rajendran, S., & Srinivas, S. (2020). Hybrid ordering policies for platelet inventory management under demand uncertainty. *IISE Transactions on Healthcare Systems Engineering*, *10*(2), 113–126.

Roberts, C. J., Pärn, E. A., Edwards, D. J., & Aigbavboa, C. (2018). Digitalising asset management: Concomitant benefits and persistent challenges. *International Journal of Building Pathology and Adaptation*, *36*(2), 152–173.

Samani, M. R. G., Hosseini-Motlagh, S. M., & Homaei, S. (2020). A reactive phase against disruptions for designing a proactive platelet supply network. *Transportation Research Part E: Logistics and Transportation Review*, *140*(1–37), 102008. 2020.

Stanger, S. H. W., Yates, N., Wilding, R., & Cotton, S. (2012). Blood inventory management: Hospital best practice. *Transfusion Medicine Reviews*, *26*(2), 153–163.

Sterbenz, J. P. G., Smith, P., Çetinkaya, E. K., Jabbar, A., Rohrer, J. P., Schöller, M., & Smith, P. (2010). Resilience and survivability in communication networks: Strategies, principles and survey of disciplines. *Computer Networks*, *54*(8), 1245–1265.

Terzi, S., & Cavalieri, S. (2004). Simulation in the supply chain context : A survey, *Computers in Industry*, *53*, 3–16, (2004).

Van Dijk, N., Haijema, R., Van Der Wal, J., & Sibinga, C. S. (2009). Blood platelet production: A novel approach for practical optimization. *Transfusion*, *49*(3), 411–420.

World Health Organization. (2011). Maintaining a safe and adequate blood supply during pandemic influenza: Guidelines for blood transfusion services. [Online]. Retrieved from: https://www.who.int/bloodsafety/publications/WHO_Guidelines_on_Pandemic_Influenza_and_Blood_Supply.pdf

Yaghoubi, S., Hosseini-Motlagh, S. M., Cheraghi, S., & Gilani Larimi, N. (2020). Designing a robust demand-differentiated platelet supply chain network under disruption and uncertainty. *Journal of Ambient Intelligence and Humanized Computing*, *11*(8), 3231–3258.

Zahiri, B., Torabi, S. A., Mohammadi, M., & Aghabegloo, M. (2018). A multi-stage stochastic programming approach for blood supply chain planning, *Computers & Industrial Engineering*, *122*, 1–14, February 2017.

Zheng, N., & Lu, X. (2009). Comparative study on push and pull production system based on Anylogic. *International Conference on Electronic Commerce and Business Intelligence*, 455–458. Beijing, China. doi:10.1109/ECBI.2009.26