# Blood Inventory Management: Hospital Best Practice

Sebastian H.W. Stanger, Nicola Yates, Richard Wilding, and Sue Cotton

**Blood is a perishable product, and hence good management of inventories is crucial. Blood inventory management is a trade-off between shortage and wastage. The challenge is to keep enough stock to ensure a 100% supply of blood while keeping time expiry losses at a minimum. This article focuses on inventory management of red blood cells in hospital transfusion laboratories to derive principles of best practice and makes recommendations that will ensure losses due to time expiry are kept to a minimum. The literature was reviewed to identify available models for perishable inventory management. Historical data from the UK blood supply chain was analyzed to identify hospitals with good inventory management practice and low wastage levels. Transfusion laboratory managers in the selected hospitals were interviewed in 7 case studies with the aim of identifying drivers for low wastage and good inventory management practice. The findings from the case studies were compared with the literature. The extant literature asserts that the drivers for good inventory performance are the use of complex inventory models and algorithms. This study has found this not to be the case. Instead, good performance is driven by the quality of transfusion laboratory staff, who must be skilled, regularly trained, and experienced. Electronic crossmatching, transparency of the inventory, and simple management procedures also facilitate good performance.**
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BLOOD COMPONENTS REMAIN a scarce and precious resource [1-4], this is despite the fact that over 1.9 million units of blood are donated in England and North Wales every year, 0.9 million in Canada [5], and between 4.3 and 4.9 million whole blood donations have been collected in Germany annually over the last 10 years. In the United States, buying blood accounts for about 1% of total hospital spend, as blood is utilized in many procedures [6]. The nature of the blood supply chains established across the world is not consistent. They differ in the structure of hospitals (private vs state), the type of supply (free vs paid donations), pricing for blood, the distribution of blood, and the handling of shortages [7]. All systems, however, have the same objectives, to provide sufficient supply while keeping wastage to a minimum.

Using blood units before they time expire allows them to be used for treatments and hence reduces unnecessary costs. Improving blood inventory management practice reduces losses due to time expiry and facilitates the efficient use of blood. Maintaining the critical balance between shortage and wastage is the key to good blood stocks management. Good inventory management performance entails carrying enough stock to guarantee 100% availability while at the same time minimizing time expiry [8,9]. Failure to meet these 2 objectives can result in a hospital transfusion laboratory not being able to meet clinical demand. While excess stock will lead to unnecessary costs for the health-care system; in hospitals across the world, economic considerations are becoming increasingly important and are therefore being used to control precious resources such as blood [10]. Wasting a unit of blood is also a waste of the donors' time, effort, and contribution which in the United States, Scotland, England, and Wales, for example, is made on an entirely voluntary basis [7]. In a study carried out by the World Health organization (WHO), of the 124 countries investigated, only 49 (39.5) had reached 100% unpaid voluntary blood donation [11]. Wastage can occur at many points across the blood supply chain [8,12]; however, for example, in the United Kingdom and Germany, in recent years, wastage in hospitals has been significantly higher than wastage in blood centers as shown in Figure 1.

Inventory management and distribution of blood are seen as major components of the cost for blood [13]. Hence, both efficient management of blood inventories and logistics can contribute to a reduction in the overall cost of blood. Various approaches have been proposed to reduce the use of blood, and hence its cost; these have been discussed in the wider literature along with a number of studies looking at the storage of blood and its impact on supply [14-16]. Therefore, this research article will focus on a review of inventory practice

*From the Friedrich-Alexander-University, Erlangen-Nuremberg, Germany; Cranfield School of Management, UK, and NHS BT, UK.*

*Address reprint requests to Sebastian H. W. Stanger, Friedrich-Alexander-University Erlangen-Nuremberg, Lange Gasse 20, 90403 Nuremberg. Germany.*

*E-mail: sebastian.stanger@wiso.uni-erlangen.de*
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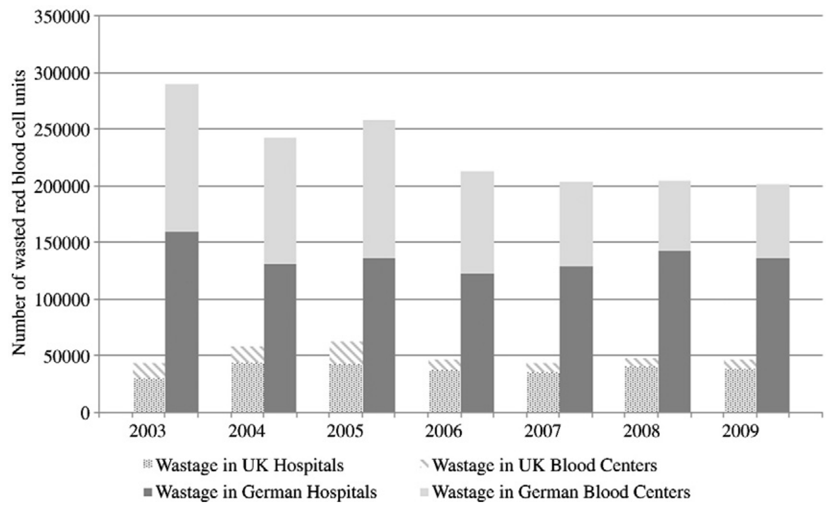


**Fig 1. Comparison of annual wastage of red blood cell units in the United Kingdom and Germany. (Data from the Blood Stocks Management Scheme [12] and the Paul Erlich Institute. [4])**

in hospitals. This article has 2 key objectives, to review the available literature on generic perishable inventory management and in doing so evaluate potential models that can be applied to the blood supply chain. Second, the article will identify the key drivers for good blood inventory performance by investigating practice in hospitals that have minimized their wastage and compare these with the findings from the literature.

## LITERATURE REVIEW

Literature on inventory management within the blood supply chain is rather limited. However, blood is a perishable and deteriorating product, and therefore, more general perishable inventory theory can potentially be applied to its management. Techniques used in industrial environments, for example, just in time, are not suitable for the blood supply system due to the consequences of an inventory shortage [17]. The majority of the extant literature is specifically related to the development of inventory theory within the blood supply chain management context and has concentrated on the development of a variety of increasingly complex inventory models based on a range of analytical and simulation techniques. This has been done on the premise that, by improving the complexity and, by extension, the accuracy of the inventory models used to manage the blood supply chain, wastage can be reduced.

Research in blood inventory management dates back to the 1960s [18,19]; there have been 2 major periods of activity, the 1970s and the 2000s. In 1973, in the first article of note, Jennings [20] described the fundamentals of how the blood supply chain operates and identified the 3 key measures of performance: shortage, outdating/wastage, and cost of information and transportation. Brodheim et al [21] went on to develop an inventory model based on the average age and average wastage of blood units using a Markov chain approach. Cumming et al [22] subsequently developed a planning model for the collection of donations and a basic model for issuing units to hospitals. Prastacos and Brodheim [23,24] published a prototype computer-based regional distribution model implemented in the United States called Programmed Blood Distribution System (PBDS). Taking a different approach, Cohen and Pierskalla [25] developed target stock levels for hospital blood banks derived from data provided by 1 US hospital and 1 blood center. In a later article, the last of this period of research activity, Prastacos [9] reviewed the literature looking at various models from an operations research point of view.

There is then a gap of nearly 20 years before Owens et al [26] analyzed the impact of the average age of blood units on the inventory performance and found that the average age varied from blood group to blood group. They concluded that an extension of shelf life had the potential to yield significant reductions in wastage. Hence, inventory management is not the only factor that impacts on the wastage of blood components. In another study from a supply chain perspective, Spens [27] identified collaboration and "doing things together" as a driver for good performance in the blood supply chain.

The establishment of the Blood Stocks Management Scheme (BSMS) in the United Kingdom and the instigation of a large database monitoring stock levels and wastage rates in hospitals and blood centers has opened new possibilities in blood inventory management research [28]. The availability of these new data has led to greatly improved transparency and consequently an increased understanding of blood inventory management and improved visibility of the blood supply chain. This has been coupled with improvements in computer technology, which have led to the availability of simulation tools with sufficient power to build meaningful models of this extremely complicated process. Various approaches to employ simulation techniques (such as discrete event simulation and level crossing techniques) have been carried out, concluding that simulation can help decision makers to make less risky decisions regarding changes in the supply chain [29-31]. A recent study by Perera et al [32] based on a survey of 265 UK hospitals identified a number of additional factors for efficient inventory management. The research showed that reducing the reservation period for reserved units (assigned inventory) leads to lower inventory levels and reduced wastage. In addition, computer-assisted ordering processes and training programs were identified as having a significant impact on the amount of stock held.

It is important to note that all of the models and approaches identified in the academic literature have limitations and weaknesses, as, by their very nature, all models are based on assumptions and require defined inputs. For example, various inventory models consider the so-called costs of lost sales or shortage costs in case of a stock out; however, due to the fact that it is hard to obtain these costs, simple ordering policies are often applied [33]. Mattsson [34] argued that simplifying assumptions made in inventory control models have a negative effect on their validity, and hence, systems built on such models cannot be expected to perform as well as anticipated. Småros et al [35] confirm this by admitting that imposing strict assumptions leads to distorted results; therefore, the models do not depict reality and cannot be applied.

This section has summarized the findings from the review of the blood inventory management literature. As has been mentioned previously, this literature is rather limited; however, as a perishable and deteriorating product, blood represents a subset of the broader field of perishable inventory management literature and therefore should be considered in this context. Table 1 summarizes the major models identified in a review of the more general perishable inventory literature. In each case, it provides a summary of the model together with the model pros and cons. Pros are indicated with the + symbol and cons are listed with the – symbol.

It is found that, due to the added complexity of the presence of both assigned and unassigned inventory, most of the general models from perishable inventory theory discussed in Table 1 are not applicable. 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 [23,25,31,39,50,52]. This academic work creates the impression that the adoption of more advanced and complex inventory management models leads directly to improved performance within the blood supply chain by determining optimal order quantities and additionally or alternatively optimizing distribution.

## METHODOLOGY

The objective of this exploratory research is to identify how good inventory practice can support a reduction in wastage of red blood cells (RBC) units in hospitals and how it compares with the findings from the literature. Data covering 277 hospitals in England and North Wales was provided by BSMS [28] in 2009. These data were analyzed to identify hospitals with low wastage levels of RBC. The database used for analysis contains information relating to inventory management such as

- hospital type and profile
- stock levels in hospitals and blood centers
- age distributions and remaining shelf lives of red cell units
- issues to hospitals
- wastage in hospitals and blood centers (number of units and reason)

A performance indicator, "wastage as percentage of issues" (WAPI) [53], was used to compare and rank hospitals. WAPI is a metric compiled of

**Table 1. Summary and Evaluation of Models Identified in Perishable Inventory Literature**

| Author | Summary | Pro (+)/Con (−) |
|---|---|---|
| *Early research and reviews* | | |
| Cumming et al [22] | Imbalances in demand and supply | − Focus on collection |
| Brodheim et al [21] | Inventory model based on average age and average waste using Markov chain approach | − Assumption: shelf life 21 days |
| Prastacos and Brodheim [23] | Prototype blood distribution system based on simulation including a set of SOPs. | + Findings derived from simulation<br>− Outdated model, more refined models available<br>+ Implementation in New York verified findings |
| Cohen and Pierskalla [25] | FIFO system delivers lowest wastage. Model based on EOQ theory trading off wastage against shortage | + Seminal work<br>− Limited sample size due to limited computing capacity<br>+ Results can be statistically verified |
| Kendall and Lee [36,37] | Goal programming model proving that stock rotation reduces the wastage | + Seminal work<br>+ First work focusing on stock sharing and redistribution |
| Nahmias [38] | Review of perishable inventory theory<br>Classifies models into fixed and random lifetime | + Proves that FIFO is very hard to achieve in reality<br>+ Approximations are more fruitful than exact calculations |
| Sirelson and Brodheim [39] | Review of different policies for platelet distribution<br>Developed a model using regression to identify the optimum order quantities | + Uses simulation to evaluate effects of weekend deliveries |
| Raafat [40] | Review of inventory models for production and replenishment policies<br>Categorized products into fixed lifetime and decaying products | − Blood components classified as fixed lifetime<br>+ Reviews based on simple and applicable models |
| Goyal and Giri [41] | Review on inventory models for perishable goods<br>Categorized goods into random and fixed lifetime | + Seminal work<br>− Blood inventory management not mentioned |
| *Available models* | | |
| Wu et al [42], Jammernegg and Kischka [43], Tekin et al [44] | News vendor model | + Some similarities with blood supply<br>− Based on profit maximization not service quality<br>− Specialized models are too complex with too many assumptions |
| Kopach et al [31] | Revisited queuing models and used level crossing techniques to identify optimal quantity | + Tracks only oldest unit<br>− Complex model<br>+ Splits urgent and nonurgent demand<br>+ Very good approach |
| Lodree and Uzochukwu [45] | Reviewed the impact of deterioration on demand and the impact of customers on FIFO | + Shows weakness of FIFO models |
| van Donselaar et al [46] | Compared different approaches with how supermarkets manage perishable goods using automated store ordering systems | + Many similarities to blood supply chain<br>+ Main strength is the simplicity |
| Goh et al [47] | Model focusing on batch sizes for donations and the impact on inventory levels and wastage | − Only very limited focus on hospitals and hospital inventories |
| Lin et al [48] | Model with time-varying demand, deterioration, equal review periods, and a fixed planning horizon | + Many similarities with blood supply chain<br>− Allows backlogs |
| Hariga [49] | Inventory policy that identifies optimal replenishment schedules | − Model is too rigid and does not allow ad hoc and emergency deliveries<br>− Assumes same shelf life for all products |
| van Dijk et al [50] | Target stock level model for platelet production based on real data from a Dutch blood bank | + Verification of findings<br>+ Reduction of time expiry by 15% to 20% |
| Broekmeulen and van Donselaar [51] | Inventory policy based on target stock levels with a fixed review period including demand profiles in weekly patterns | + Assumptions meet requirements of blood inventory management<br>+ Simplicity of the model |

**Table 2. Types of Wastage and Wastage Distribution in Hospitals in 2008**

| Code/ Abbreviation | Explanation | Contribution to Total Wastage (%) |
|---|---|---|
| TIMEX | Time expired: Units exceeding their shelf life have to be discarded and are recorded with the TIMEX code. | 70 |
| OTCOL | Out of temperature control–outside laboratory: Blood units being exposed to ambient for more than 30 min cannot be returned to the main stock refrigerators due to regulatory issues in the United Kingdom and have to be discarded. | 22 |
| MISC | Miscellaneous wastage is wastage not classified in the other categories, such as dropping a unit of blood or damaging the packaging, which results in wastage. | 6 |
| FF | Refrigerator failure: In case of a major failure of the refrigeration, the content of the refrigerator has to be discarded. | 2 |

different types of wastage (time expiry, out of temperature control, refrigerator failure, and miscellaneous) and is calculated as follows [53]:

$$WAPI\ (in\ \%) = \frac{\text{sum of wasted blood units for time } t}{\text{sum of blood units issued to the hospital for time } t} \times 100$$

WAPI shows the percentage of units wasted over the period analyzed: the lower the ratio, the better the performance. It provides a comparable metric independent of the hospital type and size.

Table 2 shows the different wastage classifications along with their associated wastage codes. The table also presents the typical proportion of wastage allocated to each code at an aggregate level for all hospitals. It can be seen from the data that time expiry (TIMEX) is the most common cause of wastage.

To prevent bias in the analysis, the hospitals were clustered by size, and each cluster was analyzed independently. This approach will ensure that a comprehensive picture of the differences and commonalities in stock management in hospitals of different sizes is created. Hospital size is an important factor. In larger hospitals, the order volumes are larger and deliveries are often more frequent. Additionally, larger hospitals tend to have more complex medical and surgical services and hence differing demands for blood when compared with smaller hospitals [8]. These factors will affect the processes in the hospital transfusion laboratory.

**Table 3. Nationwide Baseline WAPI Values for all hospitals**

| | Year | | | |
|---|---|---|---|---|
| | 2005 | 2006 | 2007 | 2008 |
| Nationwide WAPI (%) | 2.33 | 2.06 | 1.98 | 2.27 |

This information is used for the evaluation of hospitals.

To understand what good performance means, the system-wide WAPI for all of the hospitals was calculated on an annual basis for the last 4 years to establish a base line measure for comparison, this is shown in Table 3.

Using the baseline WAPI as benchmark, 7 hospitals with exceptionally low wastage levels have been selected for the case studies. Table 4 shows the WAPI for the 7 hospitals.

Once the best performing hospitals were identified the transfusion laboratory managers of these hospitals were interviewed to identify what inventory policies and practices were utilized.

### *Interview Methodology*

Transfusion laboratory managers in the selected hospitals were contacted by the BSMS in May 2009 to request their participation in the study. The purpose and the methodology of the study were explained. Once their agreement was obtained, an interview protocol was circulated via email. The interview protocol was designed to identify how blood inventory is managed. This incorporated the evaluation of the models, tools, algorithms, and approaches applied in the selected hospitals to identify drivers for good performance. The open-ended questions focused on the rationale behind decisions about stock levels, replenishment orders, automated inventory management processes, allocation of blood units to patients, and order patterns. A format that focused on open-ended, uncoded questions was selected for the interviews, as they

**Table 4. Inventory Performance Indicator for the Hospitals Selected for Interview Based on WAPI**

| | Hospital | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| WAPI (%) | 0.302 | 0.471 | 0.386 | 0.980 | 0.262 | 0.372 | 0.267 |

allow flexibility regarding the direction of the questions and do not exclude important areas by restricting or predefining the possible answers [54]. Before circulating the questions, the interview protocol was pretested with independent NHS staff to ensure that all logistics and transfusion terminology was correct and did not lead to misunderstanding and hence biased results.

Seven formal case study interviews took place in the first half of July 2009, 4 were undertaken face to face and 3 were undertaken by telephone conference. The duration of the interviews ranged between 35 and 150 minutes. Typically, the interviews lasted 60 minutes. The interview guideline was divided in 4 major sections:

1. *Stock levels:* Processes, models, equipment, and tools that are used to capture and define stock levels. The aim was to identify how target stock levels are set and adjusted and the corresponding methods, tools, and monitoring processes used. The interviews also discussed safety stock policies, safety stock levels in operation, and the methods used to set and adjust them. Strategic decisions to not stock certain blood groups and the reasoning behind such decisions were also explored.
2. *Replenishment orders:* Processes to replenish blood components and how decisions are made in this context were discussed. This included the methods used to calculate order quantities and how these methods are reviewed and adjusted over time. The questions also investigated order patterns, review periods, and the triggers for placing orders.
3. *Inventory management principles:* The questions focused on standard operating procedures (SOPs), training of staff, and the use of special incentives and initiatives aimed at the reduction of wastage in hospitals. This part of the interview reviewed the process from receipt of the unit of blood by the hospital until transfusion to a patient.
4. *Inventory management tools and equipment*: Strategic and general questions were asked about the equipment and techniques used to manage and monitor the inventories in the hospitals including how units are tracked and how remote storage refrigerators are monitored.
5. *Allocation of units to patients:* The questions included crossmatching techniques, the reservation period, and maximum surgical blood ordering schedules (MSBOS).

As this research project was exploratory in nature, it was important to ensure that the case studies generated valid, reliable, and generalizable results. Once the interviews were completed, interview transcripts were reviewed by the research team, and key themes and insights were identified. This was undertaken by clustering the material from all sources into different categories for each case individually. The questions and subheadings from the interview protocol were used as a starting point in building categories. The interview transcripts, information from site visits, and archival data were then clustered into these categories. While clustering the information, the categories have been discussed iteratively within the research team to get multiple perspectives on the facts preventing biased conclusions. This ensured that the themes are unbiased and no information was neglected or underrated or overrated. These themes were then corroborated by independent academic and NHS personnel to ensure their validity.

## FINDINGS—KEY THEMES AND DISCUSSION

The following section details the findings from the case studies.

### *Human Resources and Training*

Human resources and training was identified as a significant theme in all of the top performing hospitals. Human resource was mentioned specifically by 5 of the 7 hospitals reviewed. All hospitals confirmed that educating their transfusion laboratory staff, thereby increasing the level of awareness of what good blood inventory management means, is an essential element of good performance. Staff must be aware of the impact of their decisions on the whole blood supply chain. The blood supply chain as a system is very complex and dynamic; a wrong decision can have a serious impact on the quality of service and directly affects patients, and hence, awareness of this impact is therefore vital. Regular staff training and briefings together with the use of detailed and up to date SOPs is essential. An SOP comprises a detailed description of a process; they ensure that staff execute the process correctly. The experience of staff also impacts on performance. One hospital ensures that, when staff rotation is required, only experienced staff are in charge of crucial tasks, such as placing orders with the blood service (NHSBT) and the handling of deliveries, as the learning curve effect impacts both on the performance and the quality of decisions made.

A key element confirmed by 6 hospitals is ensuring that staff are aware of the impact of wasting a unit of blood, not only of the financial consequences, but also the impact on surgical schedules and on patients. This view of the wider implications of wasting a unit of blood, such as cancellation of treatments, the financial and operational impact, and the moral duty toward the donors, was found to be a motivating factor for staff in making better decisions. Overall awareness of staff and regular training in handling RBC units combined with detailed SOPs was mentioned by all hospitals as the key to managing red cell inventory and reducing wastage.

### *Stock Levels and Order Patterns*

In direct opposition to what is claimed in the literature, none of the hospitals surveyed used complex models or equations to readjust target stock levels on a frequent basis. All of the interviewed hospitals were unanimous with regard to the main objective of managing blood inventory: to maintain low stock levels to keep time expiry to a minimum while ensuring that stock levels are high enough to ensure supply. To achieve this, all of the hospitals have established target stock levels and maintain them by following an order-up-to policy. These target stock levels have been established based on the experience of staff and are adjusted continuously over time. In all of the hospitals, the stock levels currently in use have evolved over many years of making small incremental changes to achieve optimal levels. However, levels are not entirely rigid, and 3 of 7 hospitals adjust them dynamically on a daily basis using their experience as the rationale behind these changes. The sources of information used in the adjustment of daily orders are the number of scheduled surgeries and recurring top-up transfusions. This information, however, is not available in all hospitals in the required detail or data format; additionally, different demand profiles may affect the availability of the required data. The experience of staff plays an important role in the interpretation of this information to make the right decision for the ordering process.

### *Transparency of Inventories and Simple Procedures*

A third driver, essential for good inventory performance, is transparency and visibility of inventories. This means that it is crucial to know the stock levels in all inventory locations in the hospital and the status of all RBC units. All hospitals stressed that it is vital that inventory levels are checked frequently. This inventory includes any remote refrigerators in addition to the main blood bank inventory location. Benefits can only be derived from this information if the information is included in the process of order quantity calculation.

In contrast with the discussions within the academic literature simple "rule-of-thumb" inventory procedures were seen as important to success. For example, 2 hospitals make use of a so-called "standing order." This is a fixed order that will be fulfilled by the blood service automatically. One hospital has a fixed standing order in the morning and uses a second routine delivery to adjust the stock in the afternoon. This reduces complexity and workload in the morning while ensuring blood supply and, furthermore, gives enough flexibility to react to changes in demand with a second order later in the day. However, not all hospitals get 2 deliveries per day, and hence, this approach is only applicable to certain hospitals. To prevent too high a stock level, it is important to prevent panic orders. Therefore, inexperienced staff must be aware of all of the different stock locations and assigned inventories in the hospital. One hospital reduced the physical storage capacity to ensure that nobody placed panic orders because stock refrigerators appear to be empty.

### *Focus on Freshness of Stock*

Using a strict oldest-unit-first-out (OUFO) policy or first-in-first-out (FIFO) policy was seen as the most important discipline in reducing wastage, and simple procedures are used to support an efficient implementation of these principles. Therefore, all hospitals sorted their inventories in the refrigerators by age (ie, remaining shelf life) so that the oldest units are at the front of the shelves and available for easy access. Additionally, in 1 hospital, units close to expiry were highlighted with a red card to enable visual distinction.

The FIFO principle has been applied at various points within the supply chain to good effect. Two hospitals make use of the blood center stock level data provided by the BSMS. With this information, they draw conclusions about the age of the units in the blood centers and adjust their orders accordingly to prevent them from receiving too many old units. As blood centers work on a strict FIFO policy, high stock levels indicate that a blood center is currently issuing older blood when compared with lower stock levels.

All managers split larger orders into a number of smaller orders with the purpose of ensuring that the units received have a range of different shelf lives. This is done to avoid increased pressure on the transfusion laboratory if a large number of units time expire on the same date. This also reduces the risk of receiving a large delivery of units having a very short remaining shelf life from the blood center.

### *Internal Collaboration within the Hospital*

Collaboration with medical and surgical staff, awareness of issues with units reserved for patients, and critical questioning of orders and requests are all very important factors in enhancing performance and were mentioned by 5 hospitals in this study. The size of the current assigned inventory is a key factor in this. If the stock levels in the assigned inventory can be reduced, then flexibility in using and allocating available units to other patients can be increased and wastage of valuable shelf life avoided. For example, some transfusion laboratories adjust internal orders and requests according to their predefined MSBOS, which defines the maximum number of units issued for each standard treatment. The aim of this is to reduce the number of just-in-case orders by medical staff and thus attempts to reduce the number of units going into the assigned inventory. The MSBOS quantities are based on experience of the number of blood units required for certain surgeries and treatments. The main concern of the transfusion laboratory managers was that most orders and requests are just-in-case orders. The blood may or may not be required but is always placed in the assigned inventory waiting to be either transfused or returned after the crossmatch release period with a lower remaining shelf life. By collaboration with key stakeholders, it was possible to reduce the just-in-case orders and hence wastage. This is in line with the findings of Spens [27].

### *Electronic Crossmatching*

Another efficient tool in reducing the number of units in the assigned inventory is electronic crossmatching [55]. Electronic crossmatching is widely used in the larger hospitals, who confirmed that a reduction in assigned units can be achieved and the number of time expired units could be reduced due to more flexible allocation of units to patients. One hospital uses the benefits of electronic crossmatching to enhance internal collaboration. The increased flexibility meant they could offer a service level agreement guaranteeing a maximum lead time for crossmatched blood. This dramatically reduced the number of units in the reserved inventory and increased trust between the departments in the hospital.

## CONCLUSIONS AND RECOMMENDATIONS

Interviews with blood inventory managers in the top performing hospitals revealed 6 key themes that together drive good performance in blood stocks inventory management. These themes are human resources and training, stock levels and order patterns, transparency of inventories, simple inventory procedures, focus on freshness, and internal collaboration within the hospital. All of these themes highlight the importance of having high-quality, trained, and experienced staff. These staff must be aware of the wider implications of wasting a unit of blood, be able to apply simple inventory management techniques, and collaborate with clinical staff outside of the hospital laboratory. These findings are contrary to what is claimed in the academic literature, which suggests that it is complex policies, models, and techniques that are the key drivers to low wastage levels in the blood supply chain. The results of the case studies presented in this study reveal that these approaches are not applied in reality and that before implementing complex processes for the calculation of order quantities and target stock levels, wastage can be reduced by focusing on other factors.

Based on the findings of this exploratory research, the following recommendations for improvements in blood inventory management are made.

*Human Resources and Training*

Decisions regarding order quantities and stock levels should be based on experience rather than complex equations. This study emphasized that experienced and skilled staff are the key to low wastage. Ensure that staff handling critical processes, such as ordering and issuing, are trained regularly and that fluctuation and rotation rates in these staff positions are kept low.

*Stock Levels and Order Patterns*

Order patterns have a major impact on wastage. When large quantities of blood are required, use a number of smaller orders rather than a single large order. This prevents delivery of large numbers of units with the same expiry date and hence allows more flexibility in the usage of these units. Monitor stock levels carefully and regularly. Adjust target stock levels when required, incorporating available information about scheduled surgeries. To prevent excess inventory, critically review storage capacity, as large stock refrigerators may appear empty, and this could lead to panic orders. In addition, provide guidance for inexperienced staff. This could be in the form of visible standard order quantities on the stock refrigerators.

*Transparency of Inventories*

Transparency of inventory is a key lever for low wastage, as better information about the locations and quantities of blood components in the hospital leads to more accurate decisions about order quantities and hence lower wastage. Therefore, the status and location of all blood units in the hospital must be visible to decision makers at all times. This can be achieved either with IT support or using paper-based lists registering the locations of units; attention to detail is vital no matter which method is used.

*Simple Inventory Procedures*

Simple processes are highly effective in managing blood inventories efficiently. For example, a piece of paper, on which the standard order quantities are printed, pinned onto issue refrigerators reduces the chance of making mistakes.

*Focus on Freshness*

A major lever in reducing wastage is a strict focus on the freshness of blood units. Ensure a strict OUFO policy for issuing refrigerators in hospital blood banks is applied; this makes certain that the oldest units closest to expiry are used first and keeps the remaining stock as fresh as possible. Organize refrigerators so that units are collated by remaining shelf life and the oldest units are physically highlighted and placed at the front.

**Table 5. Summary of Key Findings and Recommendations From the Interviews Carried Out With Transfusion Laboratory Managers, Grouped Into the Six Key Themes Identified**

Stock levels
- Target stock levels based on experience are adjusted continuously
- Demand profiling to adjust on daily demand patterns
- Use information about scheduled treatments
    - Careful handling of recurring orders
- Full transparency of stock levels including remote and issue refrigerators
    - Frequent monitoring
- Consideration of recurring and planned transfusions

Order patterns
- Avoid panic orders
    - Keep storage capacity low
    - Train staff
- Split big orders into several small orders to get different shelf-lives
- Make use of standing orders to reduce workload and replenish using “top-up orders”
- Use action levels and predefined order quantities for “out-of-hours” time to prevent panic orders

Issuing
- Strict OUFO principle
- Store units sorted by age and use visual highlighting for units close to expiry
- Try to keep assigned inventories as low as possible
- Question and challenge internal requests for blood to keep assigned inventories low and reduce just-in-case requests
- Electronic crossmatching reduces assigned inventories

Remote refrigerators
- Monitor stock levels frequently
- Allow the removal of reserved blood units from remote refrigerators and assigned inventory when a patient is found for instant transfusion.
- Check regularly and return units to main storage

Human resources
- Train staff and make staff aware of the financial impact of wasting a unit
- Regular training and refreshing courses
- Motivate staff to keep wastage low
- Ensure that experienced staff are placing orders and handling incoming deliveries

Collaboration
- Motivate and incentivize hospitals to share knowledge with other hospitals
- Reduce mistrust between hospitals
- Reduce mistrust between departments in hospitals
- Use internal service level agreements to generate trust.

### *Internal Collaboration Within the Hospital*

Improving the collaboration within the hospital has a huge potential for reducing wastage. Motivating staff to share information and collaborate leads to lower wastage rates and increased flexibility in the transfusion laboratory. Clinical staff must share information related to planned surgeries to allow the transfusion laboratory to use it in their ordering decisions. Using electronic crossmatching and setting up internal service level agreements reduces the number of units reserved crossmatched in the assigned inventory on a just-in-case basis wasting valuable shelf life. Table 5 summarizes the key findings and recommendations.

Based on the above, it is clear that further research is required to explore the reasons why the complex models proposed in the literature are not used in practice, and if used, any further improvements in wastage could be achieved in the "real world."

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