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Designing an optimal inventory management model for the blood supply chain

Synthesis of reusable simulation and neural network

Monireh Ahmadimanesh, PhD[a], Ahmad Tavakoli, PhD[a,*], Alireza Pooya, PhD[a], Farzad Dehghanian, PhD[b]

Abstract

Blood supply managers in the blood supply chain have always sought to create enough reserves to increase access to different blood products and reduce the mortality rate resulting from expired blood. Managers' adequate and timely response to their customers is considered vital due to blood perishability, uncertainty of blood demand, and the direct relationship between the availability/lack of blood supply and human life. Further to this, hospitals' awareness of the optimal amount of requests from suppliers is vital to reducing blood return and blood loss, since the loss of blood products surely leads to high expenses. This paper aims to design an optimal management model of blood transfusion network by a synthesis of reusable simulation technique (applicable to all bases) and deep neural network (the latest neural network technique) with multiple recursive layers in the blood supply chain so that the costs of blood waste, return, and shortage can be reduced. The model was implemented on and developed for the blood transfusion network of Khorasan Razavi, which has 6 main bases active from October 2015 to October 2017. In order to validate the data, the data results of the variables examined with the real data were compared with those of the simulation, and the insignificant difference between them was investigated by *t* test. The solution of the model facilitated a better prediction of the amount of hospital demand, the optimal amount of safety reserves in the bases, the optimal number of hospital orders, and the optimal amount of hospital delivery. This prediction helps significantly reduce the return of blood units to bases, increase availability of inventories, and reduce costs.

Keywords: blood supply chain, deep neural network, inventory management, reusable simulation

1. Introduction

Blood is one of the most vital, yet perishable, materials in nature that has a close relationship with human life (with a life span of 5 days (platelets) up to 22 days for red blood cells). Supplying blood for the healthcare industry, treatment, and the general public is of crucial importance due to its irreplaceable role in clinical treatment. The demand for blood is relatively random, and its supply rarely follows a specific statistical pattern. To efficiently adapt the demand and supply levels is a complex process. Therefore, the management of blood and its products is a vital issue concerning human beings. Blood inventory management can be addressed at 3 interrelated levels. The first level is the individual hospital level or hospital blood bank, where the hospital's blood bank manager supervisor is the decision-maker responsible for estimating the demand for blood products, formulating ordering and collection policies, distribution and crossmatching policies, and separation policies with regard to blood components.[1,2]

In general, the safety of hospitals and health facilities is a quite significant objective, and its complete implementation by and integration with all health systems is increasingly stressed. A recent piece of legislation that encourages the application of risk management methodologies has been passed, and it aims to identify necessary preventive and corrective actions for risk reduction by investigating all the possible sources of error, the consequences of which could compromise the ability of organizations to achieve their goals. Risk management must be understood both as a health technology to increase the security of care processes through the definition of a set of principles, behaviors, organizational mechanisms of the company, and, also as an essential part of quality systems as it improves all health services and enhances the system in general by providing a better working environment for staff and better care for patients.[3]

The second level is the regional level or regional blood bank, in which the decision-maker is the director of the blood center in the region who develops distribution policies among hospitals and performs such tasks as planning for the collection, distribution, and transfusion of blood across the region.[1,2] The third level is the total level (total blood transfusion organization), in which the

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[a] Faculty of Administrative Sciences and Economics, Faculty of Administrative Sciences and Economics, Ferdowsi University of Mashhad, Mashhad, [b] Faculty of Engineering, Ferdowsi University of Mashhad, Mashhad, Iran.

[*] Correspondence: Ahmad Tavakoli, Department of Management, Faculty of Administrative and Economic Sciences, Ferdowsi University of Mashhad, Mashhad, Iran (e-mail: Tvakoli-a@um.ac.ir).

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decision-maker is the director of blood planning and coordinates regional centers.

Among these levels, blood management at the regional level is naturally more complex than that at the individual hospital level due to a large number of bases and hospitals in the regional systems, high frequency of ongoing activities, and complexity of the organizational structure.[1] In addition, prediction of blood demand at the regional level is more critical since the consequences for those with rare blood types, which are not easily available, will be more intense. To be more specific, lack of access to an appropriate blood unit may cause a delay in surgeries and, sometimes, lead to death. The waste of blood products is a serious problem, because a blood unit wasted in a certain blood bank may cause blood shortage in another bank. In addition, a person who donates a blood unit cannot do it again for the next several months. Therefore, loss of a blood unit is equivalent to the shortage of the same unit over the next several months.[4] As a result, in any region, success in blood inventory management depends on proper application of optimal and efficient methods for planning the threshold level of blood inventory, predicting consumers' demands, and developing policies for collecting, storing, and ordering blood required by consumers to provide a timely response to patients' demands.[5]

Given the importance and sensitivity of the issue of regional blood inventory management, designing an integrated inventory management model is taken into consideration since it provides proper, accurate, and scientific control over the availability of blood products such as collection, storage, reduction of blood product waste, etc. The present paper aims to develop an integrated and comprehensive model of regional inventory management. What distinguishes this study from other related papers on the medical supply chain is that it presents, first and foremost, an integrated model that is applicable to all blood distribution sites (bases) in a regional network and has been developed in such a way that no remodeling or additional cost and time is required to investigate each case. Only by updating the events can the current desired behaviors be formulated using the reusable simulation technique. In addition, the combination of reusable simulation techniques and deep neural networks facilitates predicting the behavior of sites and their consumers, even if their existing data are patternless and outdated.

The rest of this paper is structured as follows. The second part describes the research background and related literature in the relevant field. The proposed model and its relations are discussed in the third section. In the fourth section, the results of the model will be discussed and, finally, conclusion and possible suggestions for future research will be presented.

2. Literature review

The study on supply chain management of blood products as a form of a perishable product was first introduced in 1964 by Van Zeil. In the following, Rytila and Spens[6] used a simulation tool, Discrete Event Model, to improve the blood supply chain management. Their obtained results showed that simulation could help decision-makers make better decisions based on knowledge and take less risk. Katsaliaki[7] used the simulation model to effectively manage the cost of blood supply chain in the UK to test and identify inventory and distribution policies. Aghyani et al[8] provided a robust optimization model for reliable design of blood supply chain network, considering possible disturbances in blood collection facilities, blood transfusion pathways, and blood centers during the crisis. The purpose of the proposed model is to minimize blood shortage and maximize the reliability of the blood supply chain in emergencies. The parameters of blood supply and demand of donors are considered to be uncertain here. The performance of the developed model is studied using real data in Tehran, and numerical results are presented with sensitivity analysis. Li and Liao[9] attempted to control the policies of blood delivery and increase the blood supply chain level in the Taizhou city of Taiwan by means of combining genetic algorithms with the neural network. In order to improve the efficiency of the stable supply chain, Zahraeea et al[10] used a combination of dynamic and Taguchi simulation models, and obtained results demonstrated an improvement in their investigated factors.

Some researchers have focused on the regional blood supply chain. Examples of such studies include a thesis written by Yegul[11] that analyzes the policies of blood supply chain management in a regional blood network using Discrete Simulation model implemented in the Turkish blood bank. The results of the study demonstrate important improvements such as expiration rate, mismatch, and deficiency. In addition, Baesler and Sepulveda[12] used Discrete Event Simulation model to analyze and propose blood inventory policies at the regional blood center. This model shows the activities carried out in the supply chain such as blood receipt, testing, production, and inventory management. Twelve different scenarios were analyzed, out of which the best scenario aimed to reduce unsatisfied demands and waste of blood units to 3%. Applying a reusable simulation model, Blake and Hardy[5] developed and evaluated regional policies of blood inventory networks in Canada and, then, used the response surface method and nonlinear programming to develop the supplier's optimal inventory policies. By means of neural network technology, Khaldi et al[13] predicted the amount of demand for blood units (red blood cells, plasma, and platelets) in a regional blood network and, to prove the accuracy of this technique, they compared its results with those obtained by Arima technique; the performance of the former was shown superior. Further, in the same year, Hijma used a 5-state Markov decision model and simulation in his paper to reduce platelet waste at the regional level. Table 1 summarizes the literature related to blood management.[13–21]

By reviewing previous studies, one can claim that there is a great deal of literature on blood inventory management; however, more often, reducing and combating blood shortage and expired blood units has received greater attention. Further to that, a small number of articles have been dedicated to developing an integrated approach to all suppliers of blood units in a regional network. Of note, there are few practical studies on the subject of the combination of simulation and neural networks in the field of blood supply chain. Therefore, the present paper attempts to design a model that, first, is comprehensive and inclusive with respect to all of the existing databases in the network, and, second, does not require any supplier to devise a separate model. To this end, the reusable simulation technique was used. In addition, in order to accurately predict the customers' demand, the optimal amount of orders sent to customers and the optimal safety reserve for each supplier were utilized by the neural network technique. It should be noted that the advantage of combining 2 techniques of reusable simulation and neural network helps predict all customers' optimal orders in the region, which significantly reduces the return rate of blood units and increases the blood inventory available to suppliers. In other

Table 1

Literature on blood inventory management.

Article	Field	Reviewed parameters	Approach
[13]	Blood supply chain	Shortage, blood expiration	Mathematical programming
[14]	Blood supply chain	Shortage, blood expiration, and mean of inventory lifetime	Mathematical programming
[15]	Blood supply chain	Shortage, blood expiration, and ordering	Random programming and metaheuristic
[16]	Blood supply chain	Shortage, blood expiration	Simulation
[17]	Blood supply chain	Shortage, blood expiration	Simulation
[18]	Blood supply chain	Shortage, blood expiration	Simulation
[19]	Regional blood bank	Shortage, blood expiration	Randomized dynamic programming
[20]	Regional blood bank	Shortage, blood expiration	Randomized dynamic programming
[21]	Regional blood bank	Delivery expense/cost	Integer programming
[22]	Regional blood bank	Shortage, blood expiration, and ordering	Randomized dynamic programming

words, in addition to providing significant assistance for suppliers in terms of demand and delivery units, this technique will also improve customers' ordering policies.

3. Model description

The blood supply chain activities include collecting, testing, processing, and distributing blood (and its derivatives) from donors to patients for emergencies, surgical or routine medical treatments. These activities can be divided into 4 main levels of collection, production, inventory, and distribution. This chain begins by collecting blood from donors; then, it is stored and processed as a complete blood unit to remove red blood cells from other products, such as plasma and platelets; next, blood products are stored as inventory in the blood bank of a blood transfusion center, finalizing it for distribution.[23] Finally, hospitals, according to the predicted demand, place their orders to the blood centers; then, the received blood is tested and, after the crossmatching process, in case of compatibility, blood units are used for the particular patient.[24] This paper seeks to optimize the blood inventory in the blood supply chain so that a model for predicting the optimal value of inventory management of blood distribution bases in the blood supply network can be designed.

The reusable simulation approach was used due to the complexity of presenting blood flow (8 blood types) and the large number of sites and hospitals examined. The reusable simulation technique allows a single model to be used for multiple systems in a given domain (area). These models are one of the many generic models that are configured at runtime to show a specific instance of the problem. The model is particularly designed so that it can be used for different bases and, thus, there will be no need for remodeling. To simulate the data of inventory management variables, donation frequency, amount of inventory, amount of demand, delivery rate to each hospital, rate of return units for each hospital, and the order of each hospital, etc. are incorporated in the simulation model.

The neural network technique was used to predict the values of optimal inventory management, and the deep neural network was used due to the unorganized and inconsistent data of existing status. The neural network is a set of nodes and connections between them. It is also composed of a set of simple elements that forms a complex unit in relation to each other. Neural networks are designed to receive various pieces of information. The nodes are capable of receiving input, processing them, and producing output. Connections are used to transfer information between nodes, which can be either directional or bidirectional. The variables in the neural network include the amount of hospitals' blood demand and the rate of blood return units (as fines) that, after solving the model, predict the optimal rate of blood units delivered to hospitals.

The model was approved by Khorasan Razavi Blood Transfusion Organization. The names of some of these members are:

Dr Hamidreza Safabakhsh: Head of Education and Research of Khorasan Razavi Blood Transfusion Department

Dr Reyhaneh Bazargani: Head of Blood Transfusion Department and Hospital and Hemovigilance Consumption Department of Khorasan Razavi

Mr Asadollah Ilbeigzadeh: Head of Khorasan Razavi Blood Transfusion Information Technology Department

3.1. Designing simulation model—neural network

In this model, first of all, it is necessary to assess the behavior of blood bases with regard to the donation frequency, the frequency of blood return divided by the causes of return (expiration or unusability), the frequency of blood sent to the considered hospitals, amount of available reserve for each blood bank, frequency of blood transmitted to other sites in the network from their local blood transfusion sites to reduce waste and deficiency. Moreover, to determine the behavior of hospitals (consumers), the frequency of blood requested by hospitals covered by each site should be received separately and on a daily basis.

In addition to the above-mentioned issues, several assumptions for implementing the proposed model have been also considered:

1. A region-based model has been considered that includes several bases (suppliers) and hospitals (consumers).
2. At least, 3 supplier bases have been considered for using this model.
3. Four variables required for examining in the case of each supplier and consumer have been considered.
4. Blood loss/waste resulting from expiration and nonconsumption is separately calculated.
5. A provider faces demand uncertainty for blood.
6. The availability level of primary blood supply for each hospital and base is clearly determined.
7. The safety reserve for each base and hospital is specified.
8. The supplier is penalized for any shortage due to the high level of demand uncertainty.
9. Blood transfer among bases is possible.
10. It is possible to return blood from consumers to suppliers.

While implementing the simulation algorithm, feed forward neural network with 2 hidden layers is used for prediction. The variables and parameters used in this model include the following.

3.2. Variables

U: is the result of the difference between requests and returns and neural network input and is somehow a cost function.
y: target of the neural network that we seek to predict with respect to cost.
Order: The required demand by each base and customer
Send: Amount of blood delivery according to neural network prediction
Inventory: The volume of blood reserve remaining in each base

3.3. Parameters

1. Available data for training the network were used for 500 days.
2. Available data were used for network test for 231 days.
3. Each neural network training: 6000 Epoch
4. Validation times: 60 times

In this algorithm, on each day of simulation, successive steps from the supplier to the consumer are taken. At the beginning of the day, the rate of blood units entering the central blood transfusion reservoir from various blood donation bases is estimated. At the same time, the available blood levels in each hospital's reservoir are compared with its threshold. Then, each hospital orders its required blood unit from the blood transfusion center. At the central blood transfusion center, the total hospital orders are calculated and compared to the amount of inventory reservoir. In this stage, the base should calculate the scale factor through the multilayered perceptron neural network according to hospitals' requests and returns in previous days. Then, according to this factor, blood units are sent to hospitals. This factor is also used for determining hospital requests at the hospital's blood bank. This factor was calculated for 500-day training, and the optimal amounts are considered for the next 200 days. Moreover, to predict hospitals' demand, a deep neural network was trained with multiple recursive and fully connected layers. The technique was also trained in 700 days, which is capable of predicting the next 30 days. Finally, according to the formulation of the existing algorithm and the amount of consumption predicted by the neural network while assuming a certain value at the beginning of the simulation algorithm for each base, the threshold of the bases is also extracted. This process is repeated on a daily basis. This algorithm is applicable to all existing databases in the region. Figure 1 shows the simulation algorithm, and Figure 2 shows the relationships that govern the neural network technique. Y is the number of requests, and U is the number of requests returned. This method makes it possible for the amount of returns to be paid as a sum of fines in the calculations and prevents the expiration of blood units when they remain unconsumed for a while.

In the neural network cost function, a finite amount of fines is considered for return and expired blood units; accordingly, a neural network can be used to predict a possible optimal mode.

3.4. Databases

In order to implement the developed model, daily data associated with blood transfusion centers of Khorasan Razavi, Iran, covering a time span of October 2015 to October 2017 were used. The number of existing central bases (distributors) in the province from which the data were collected is as follows: 6 bases in Mashhad, Neyshabur, Gonabad, Quchan, Torbat Heydarieh, and Sabzevar. The information required to conduct this research was obtained through library studies and interviews with experts and doctors of the Blood Transfusion Organization of Mashhad. Figure 3 shows the blood allocation pattern in the Blood Transfusion Network of Khorasan Razavi.

3.5. Validation

In order to validate the algorithm, a central base out of 6 existing bases in the Blood Transmission Network located in Khorasan Razavi, Iran was considered as the sample. This base considered to be the largest base of blood production and distribution in Blood Transmission Network in Khorasan Razavi province has received the highest number of consumers. To test the validity of the model, variables including mean of hospital demands, bases' delivery, and hospital return segregated by nonconsumption and expiration date as the outputs of the simulation model are considered. Daily blood inventory at each site (base) was averaged, by month, over the years 2015 to 2016 and compared to the daily inventory averaged by month using *t* test, as observed in the simulation models. Thus, 12 samples for 3 variables considered in the *t* test model were considered. Tables 2–4 show the test results.

The results indicate that there is no significant difference between the results obtained from the simulation and the real data. Therefore, the results obtained from the simulation of the bases and hospital behavior are reliable and can be trusted.

4. Results

According to the algorithm used to optimize inventory management, the following results have been achieved by the implementation of the model in the blood transfusion network of Khorasan Razavi. These results indicate the prediction of the values of the mean demand variables, the optimal amount of hospital requests, the optimal amount of delivery by the bases, and the optimal safety reserve value. It should be noted that the results are solely limited to the central base of Mashhad. Other results of the bases can be extrapolated according to the algorithm; however, due to the complex, large quantity of such results, they have not been considered for this study.

4.1. Predicting the amount of hospitals' blood demand

Since the collected data appear quite distorted and inconsistent, the deep neural network with recursive multiple layers was used to predict the amount of hospitals' demand. The results obtained by this technique are presented in Figure 4.

4.2. Estimating the optimal amount of hospitals demands from the bases

After applying the neural network technique in the simulation algorithm, the optimal amount of hospitals' demand from the base, or hospital orders, was obtained according to which waste, returns, and deficiencies could be minimized. The results (Fig. 5) indicate that if hospitals intend to order an optimal amount to prevent deficiencies and wastes, they should request blood units

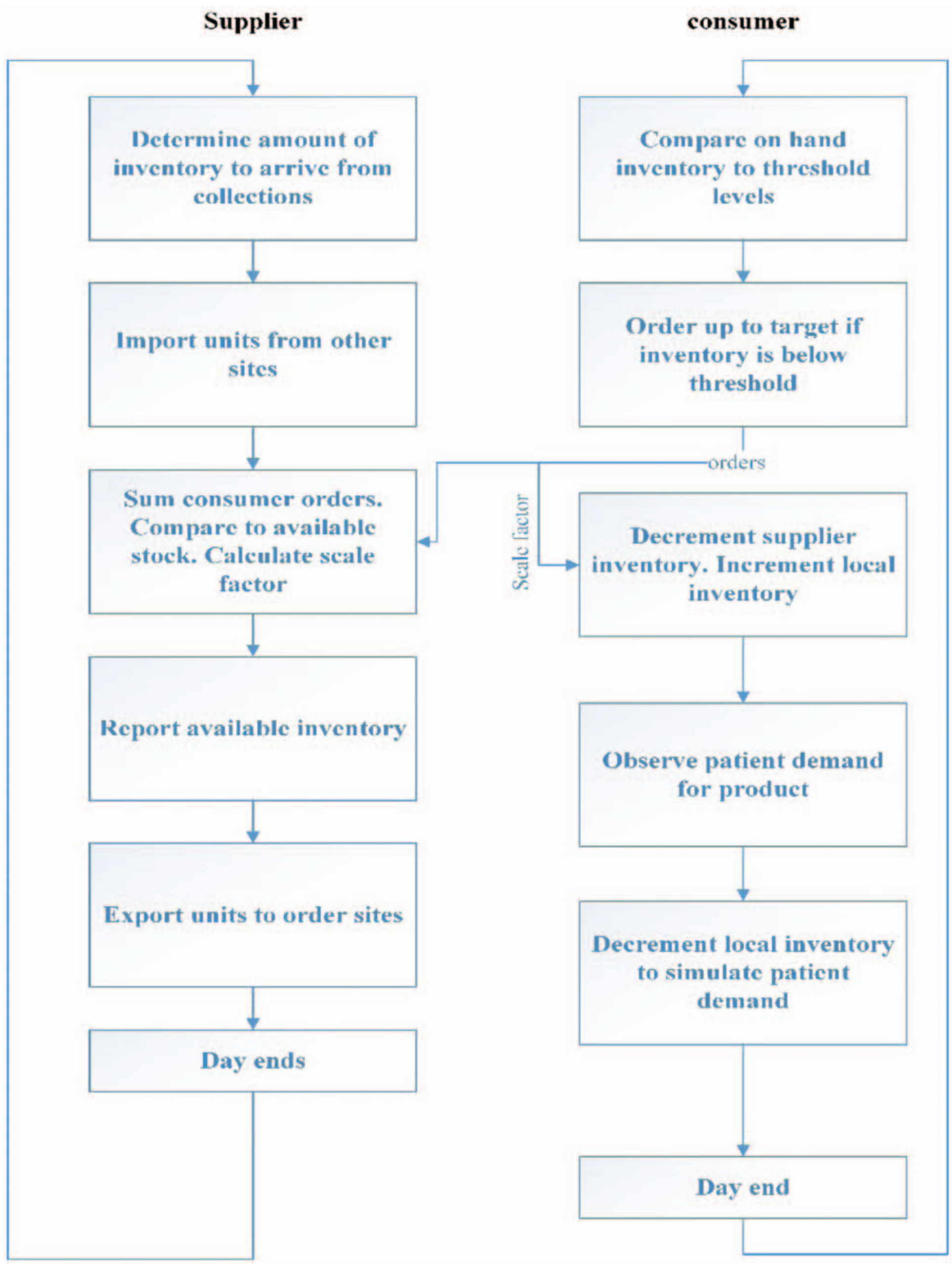

Figure 1. Conceptual flow simulation algorithm.

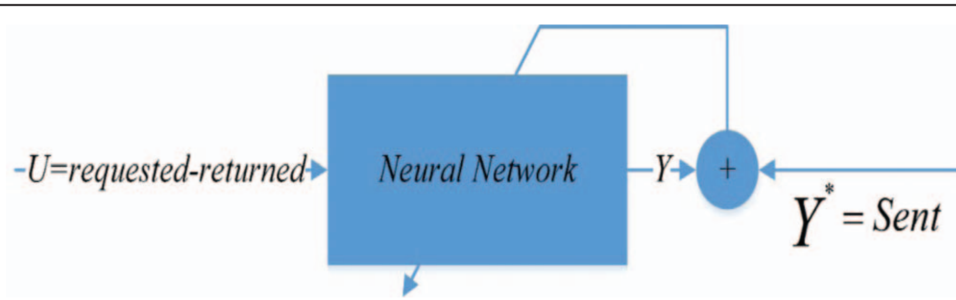

Figure 2. Relationship governing the neural network model.

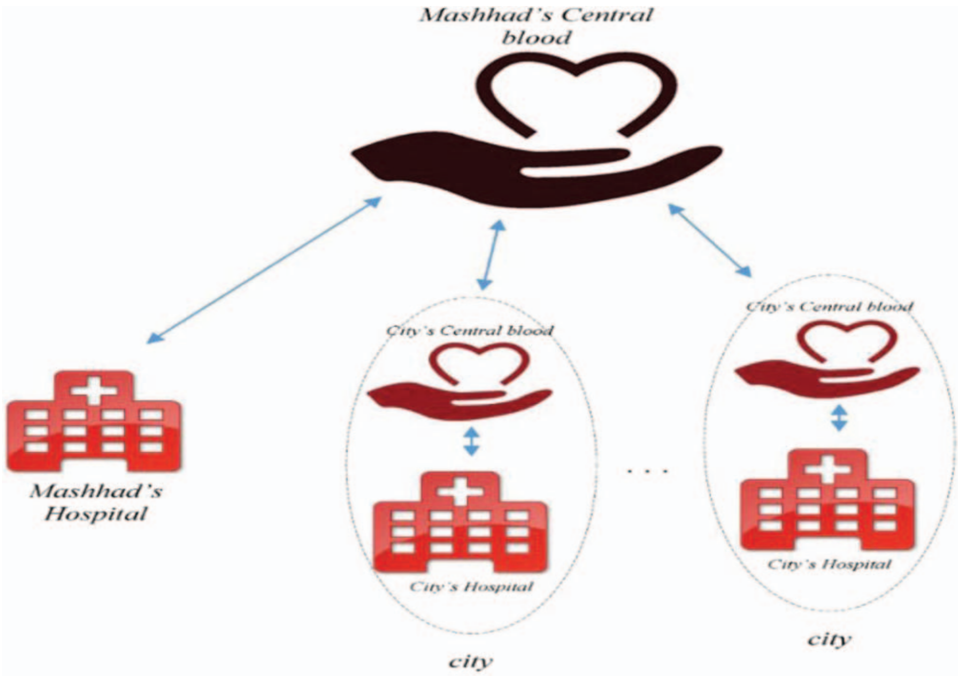

Figure 3. The process of blood allocation in the blood transfusion network of Khorasan Razavi.

according to the red lines. The difference between blue and red lines represents the presence of a gap between the current and optimal statuses.

Table 2

Statistical results of the mean required average hospital in Mashhad.

	Real data	Simulation results
Monthly mean	751.07	752.14
Standard deviation	17.71	14.32
n	12	12
P value	.967	

Table 3

Statistical results of the average delivery of Mashhad Base to hospitals.

	Real data	Simulation results
Monthly mean	668.12	672.15
Standard deviation	25.94	15.64
n	12	12
P value	.95	

Table 4

Statistical results of hospital's average return rate to Mashhad Base.

	Real data	Simulation results
Monthly mean	55.67	58.2
Standard deviation	1.82	0.95
n	12	12
P value	.978	

4.3. Prediction of the optimal delivery rates from bases to hospitals

Figure 6 depicts the results of the optimal delivery rates from the bases to hospitals. According to obtained results, in case the bases aim to ensure the least return rates from hospitals and low shortage, they should deliver blood units on the basis of red lines. The divergence between blue and red lines indicates the gap between the current and optimum conditions.

4.4. Predicting the optimal amount of safety reserve

Given the algorithm used and the predicted consumption by the neural network while assuming 1000 units at the beginning of the

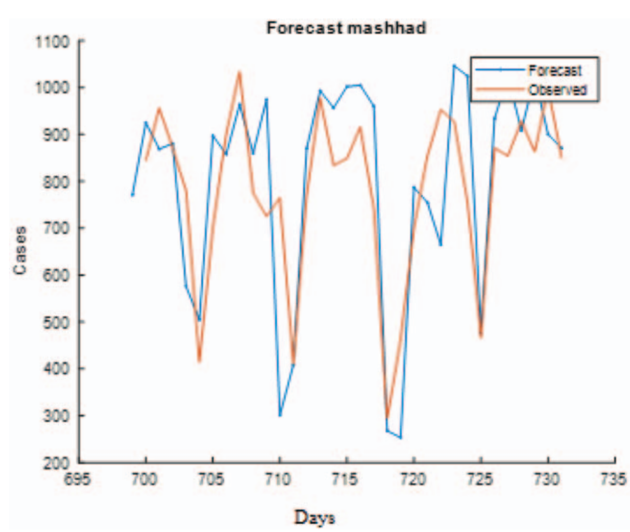

Figure 4. Existing and predicted demands.

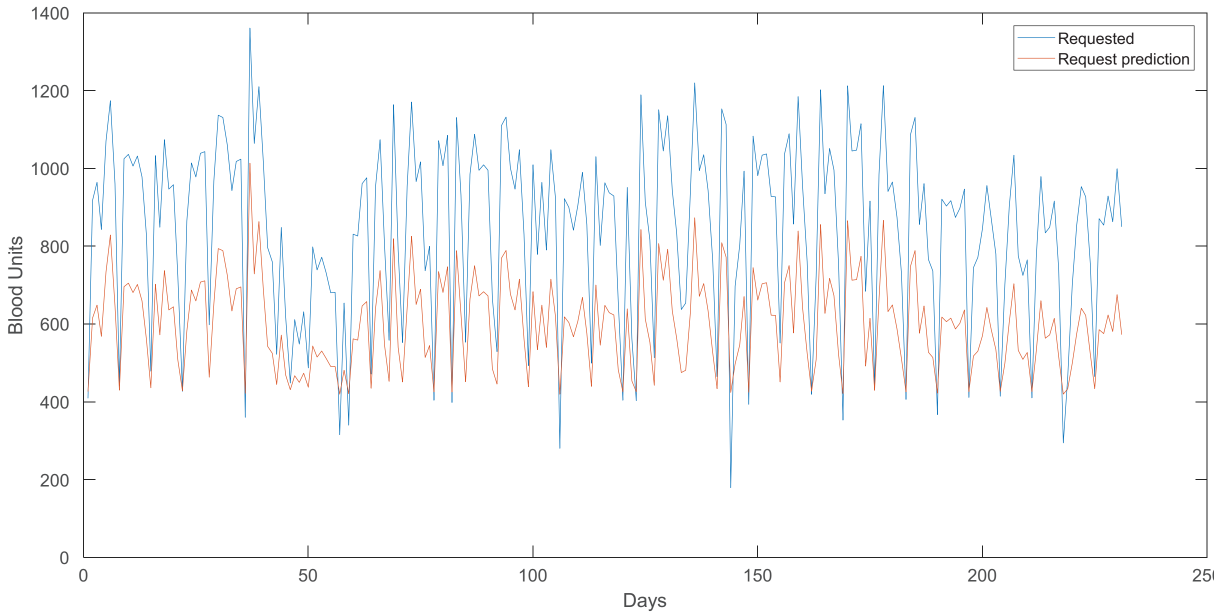

Figure 5. A comparison of the amount of request and request prediction.

simulation period, the optimal threshold for this base was determined as 5% of the inventory.

5. Discussion and conclusion

The purpose of this study is to design an optimal blood inventory management model for the blood supply chain. To this end, an artificial neural network in the reusable simulation process was used to predict the optimal behavior of suppliers and customers, resulting in a significant reduction in customers' blood return units and an increase in suppliers' inventory to avoid deficiencies. This paper also describes the application of a reusable simulation model and neural network in the field of medicine and inventory management of the regional blood supply chain network in Iran. So far, no study with this breadth on the blood supply chain has been conducted. One of the advantages of this method is an integrated and comprehensive simulation model used in this study, which is designed so that there is no need to design another separate model for each base in the region. In addition, it can be updated with existing algorithms and current and desirable behaviors. In order to prove the success of the designed model, it was implemented in the blood transfusion network of Khorasan Razavi composed of 6 central distribution centers and about 50 hospitals. The results in the case of Mashhad's base indicate that if the suppliers and customers act according to the predicted behavior, the amount of blood return will be zero and the

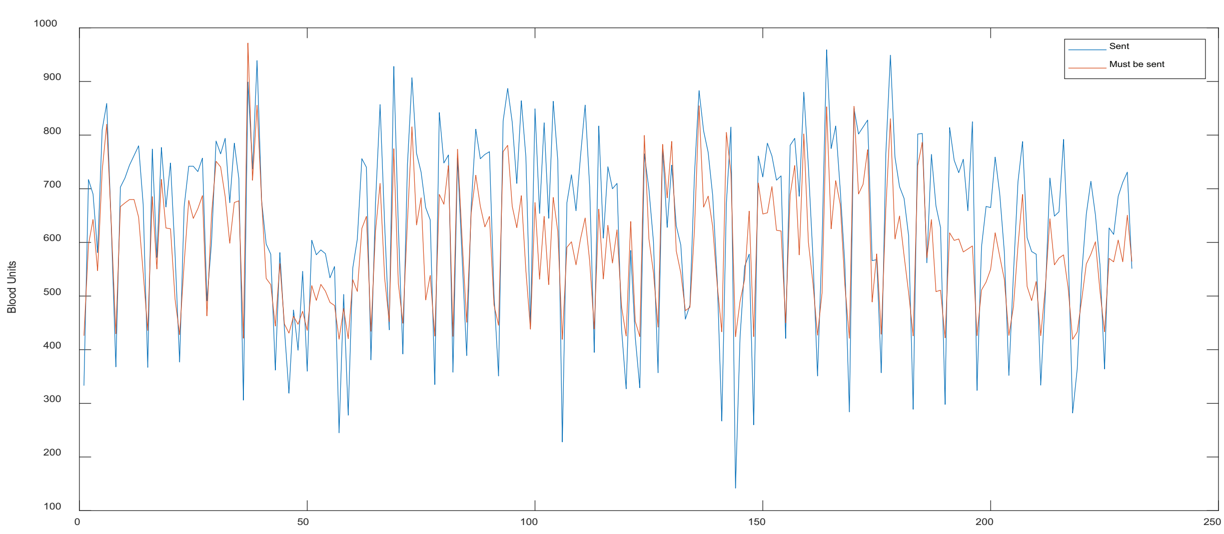

Figure 6. A comparison of the amount of delivery and delivery prediction.

inventory reservoir will contain 2000 units. In each base, the model's results were compared with the real-world data, thus proving the model's validity and reliability.

6. Practice implications

One of the problems that the current researchers have encountered in this research is the large volume of data available in the blood supply chain studied. This volume of data makes it time consuming to design a model and implement it. Therefore, in this research, the inventory management of one of the components of blood (red blood cells) was investigated and studied.

In addition, since there are 8 blood types that have not been categorized in this study, for the future research, it is recommended that the algorithm be analyzed for blood groups and other elements of the blood group separately so that the optimal process of each group/element can be predicted. Since distribution and transportation represent one of the supply chain components, it is recommended developing a model for optimizing the supply chain distribution and supply chain inventory.

Author contributions

Conceptualization: Farzad Dehghanian.
Investigation: Monireh Ahmadimansh, Farzad Dehghanian.
Methodology: Monireh Ahmadimansh, Alireza Pooya.
Resources: Monireh Ahmadimansh.
Supervision: Ahmad Tavakoli.
Validation: Alireza Pooya.
Writing – review & editing: Monireh Ahmadimanesh, Ahmad Tavakoli, Alireza Pooya, Farzad Dehghanian.

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