

**BLOOD BANK LOCATION MODEL**

*Pranita jena,*

*Dept. Of Mathematics,*

*IIT Bhubaneswar, Odisha.*

*Pranitajena2021@gmail.com*

*Namita Rani Mall,*

*Dept. of Statistics*

*Sambalpur University India-768019.*

*mallnamitarani@gmail.com.*

**ABSTRACT**

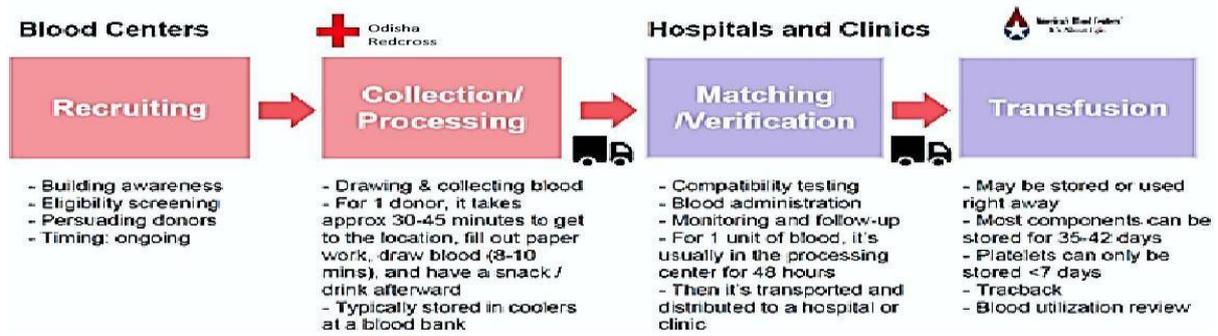
The operation of blood service facilities plays a vital role in the global healthcare system. However, due to the unique challenges associated with these services, there has been limited modeling and analysis from the perspective of supply chain network optimization. Consequently, this lack of strategic planning can hinder the efficiency of logistics and supply chain systems, particularly when it comes to selecting optimal locations for blood service facilities. The design of the blood supply network entails critical strategic decisions variables. A piecewise nonlinear optimization approach is applied to solve the model, particularly for making effective cluster location and allocation decisions. Furthermore, a sensitivity analysis is carried out to assess how different model parameters influence the overall cost of the supply chain network per unit time.

***Keywords: Blood supply chain network design, Location-allocation of blood bank, Mixed integer non-linear programming (MINLP), Piecewise non-linear optimization.***

**1. Introduction**

Blood is a life-sustaining fluid that serves a multitude of critical functions within the human body, ranging from oxygen transport and nutrient delivery to immune system support and waste removal. Its significance cannot be overstated, as it is essential for maintaining bodily functions and sustaining life. In the context of blood supply chain network design, understanding the significance of blood emphasizes the criticality of optimizing the systems involved in its processing, collection, storage and distribution. Efficiently designed blood supply chain networks are essential for ensuring the timely dispersal and accessibility of blood products to meet the requirements of medical facilities and individuals in need of treatment. In the context of the blood supply chain network design, recognizing the importance of blood underscores the

critical role of optimizing the systems responsible for its collection, processing, storage, and distribution. This intricate framework necessitates the coordination of diverse entities, encompassing blood banks, medical facilities, and transportation infrastructures, to oversee the collection, processing, storage, and dissemination of blood components. The optimization of blood supply chain networks is essential for enhancing the overall performance and effectiveness of blood transfusion services. By strategically designing these networks, organizations can minimize costs, reduce wastage, improve blood product availability, and enhance the responsiveness to emergencies and fluctuations in demand Sauri (2009). The complexity of blood supply chain management stems from several factors, including the perishable nature of blood products, stringent storage and transportation requirements, and the need to adhere to regulatory standards and quality assurance protocols. Additionally, the geographic distribution of healthcare facilities and population centres further complicates the design and operation of blood supply chains. In recent years, advancements in technology, logistics, and operations research have facilitated the development of sophisticated models and methodologies for optimizing blood supply chain networks. These models consider various decision variables, such as the capacity of blood collection centres and location, the routing and scheduling of blood transportation vehicles, inventory management strategies, and the allocation of blood products to meet demand requirements Oswalt (1976). Furthermore, the integration of information systems, data analytics, and real-time monitoring capabilities has enabled stakeholders to enhance the visibility, traceability, and transparency of blood supply chains. This, in turn, facilitates better decision-making, risk management, and quality control throughout the supply chain. Heydari et al.(2018) Despite these advancements, challenges persist in optimizing blood supply chain networks, particularly in regions with limited infrastructure, resources, and access to healthcare services. Factors such as seasonal fluctuations in demand, demographic trends, and unforeseen events, such as natural disasters or pandemics, can further exacerbate these challenges. The supply chain of blood products involves blood banks and hospitals, as illustrated in Figure 1.



**Figure 1:**

The overarching procedure concerning the supply chain of blood product. Top of Form Figure 1 shows the entire the procedure linked to the blood product supply chain commences with the Compilation phase, wherein blood units earmarked for transfusion are acquired from donors. This collection occurs either at a central blood centre or through mobile blood collection units deployed in distant areas. After meticulously adhering to rules and regulations concerning donor compliance, the collected units undergo thorough testing. Following this, the whole blood units are either stored without alteration or Separated into different components. The process involves mechanically separating into distinct components. During this procedure, the recipient's blood undergoes crossmatching against the donor's blood to ensure compatibility. Once compatibility is confirmed, specific blood units are reserved for the designated patient during the crossmatch release period fahimnia (2017).The blood bank maintains records of blood inventory and demand levels across each hospital, assuming the role of decision-maker on behalf of all stakeholders in the system. This responsibility entails minimizing overall costs and shortages within the blood supply chain. Apheresis, an alternative technique for collecting blood, entails the direct extraction of a specific blood component from a donor. This method is notably more efficient than fractionation. However, it does have drawbacks, including higher costs and longer collection durations. The selection of a collection method usually dictates the subsequent production method, except when dealing with blood units collected using a quadruple bag. In such cases, there are two available fractionation methods, and the choice is usually made when the unit arrives at the blood centre. With the multitude of production options, uncertainties in supply and demand, and factors like perish ability to consider, it's crucial to develop robust production planning strategies. These strategies need to take into account different collection methods, fractionation choices, and donation rates. In the blood supply chain, there is a delicate balance between minimizing outdated and avoiding stock outs. Holding excessively large inventories of blood products increases the risk of units becoming outdated, whereas maintaining low inventories may lead to stock outs, reducing service levels and potentially compromising patient care. Furthermore, planning tools for the blood supply chain must incorporate not only inventory policies to address uncertainty and seasonality but also consider the balance between efficiency and cost across various collection and production options. The present research develops a blood supply chain network design model for the western region of odisha, focusing on whole blood products. The objective is to optimize the supply chain network design cost, number of blood banks, influence area, shortage time period, storage temperature, and order quantity for whole blood products. Critical sensitivity analysis is performed to highlight the significance of parameters on the total supply chain network design cost of blood products and provide managerial insights.

## 2. Literature Review

Blood is a vital component within the human body, but there are instances when external sources are needed. A delay in obtaining blood in such situations can have life-threatening consequences. To address this issue, blood bank management systems have been introduced. These systems maintain a comprehensive database of blood donors, as well as the blood inventory in various blood banks and hospitals. This enables quick access to blood when needed. Recognizing the critical importance of timely access to blood, these systems play a crucial role in fulfilling this need efficiently. With the aid of blood bank systems, locating blood and its products in nearby areas becomes a straightforward process. The systems regularly update their databases to ensure accuracy. Within the blood bank management systems, a centralized database holds information about blood donors and blood banks. When a recipient requires blood, the system checks the database for compatible blood availability and operates accordingly.. A literature survey reveals several articles focusing on blood bank management systems, specifically addressing how to improve the management of blood banks and facilitate easier access for recipients compared to traditional methods. Various authors have endeavoured to enhance blood bank operations in their unique ways, and some of these efforts are discussed in the literature. For instance, Lao et al. (2004) developed a quality predictive model for Ready-to-Eat (RTE) foods, incorporating analysis under various temperature storage conditions along with decay rate considerations for inventory management. Temperature fluctuations can readily lead to deterioration in food quality. To gauge the impact on the shelf life of Ready-to-Eat (RTE) food, we compare the standard temperature settings with the observed values obtained through temperature monitoring. In a study by Cetin et al. (2009), a mathematical programming model was introduced. This model combines elements from discrete location approaches, specifically the set covering model, with continuous location models such as the centre of gravity method. The model involves three main objectives: reducing the overall fixed costs linked to blood bank locations, minimizing the distance between hospitals and blood banks, and minimizing an inequality index that acts as a fairness measure for distance distribution. It concentrates on determining the placement of blood banks across a region rather than the internal layout of blood banks within healthcare facilities. In a study by Hsu et al. (2010), a deteriorating inventory policy was formulated specifically for scenarios in which the seller employs perpetuation tools to mitigate the decline rate of products. The study outlines a solution methodology to determine the optimal shortage periods, replenishment cycles, order quantities, and costs associated with preservation technology. The main goal is to optimize the total profit per unit time. Furthermore, Nagurney (2010) introduced a structure for the intend

and reshape of bring string network. This structure enables the identification of best possible level of capacity and operational product flows across manufacturing, storage, and distribution activities within the supply chain. The objective is to minimize total costs while meeting product demands. Both design and redesign challenges are formulated as variation inequalities, illustrating that a single algorithm, utilizing the inherent network structure, can address either problem effectively. Dye et al. (2012) developed an inventory model that encompasses decision variables such as protection skill and the refill list. It considers a time-varying deterioration. .Duan et al. (2012) The authors presented inventory models specifically designed for perishable items, where the order require varies based on the inventory level. This study explores models that include and exclude backlogging. The study explores two scenarios: one where retaining inventory is beneficial and another where it is not. In the latter case, the research determines the minimum shelf space required to prevent shortages. In the model where backlogging is absent, it is assumed that any excess inventory remaining at the end of the inventory cycle is sold off at a salvage value. The efficacy of the proposed models is showcased through numerous numerical examples spanning various studies. Duan et al. (2015) investigates the best inventory management tactics for perishable goods, considering a demand rate contingent upon inventory levels. It accounts for nonnegative inventory and addresses partial backlogging during shortages, where the rate of backlog is influenced by both the quantity of backlogged demand and waiting time. Kumar (2015) The research formulates a deterministic inventory model specifically designed for perishable items with fluctuating demand over time, which can handle shortages and partial backlogging. Yang et al. (2015) introduce a deteriorating inventory model for chilled food products that accounts for food quality and remaining value. This model incorporates real deterioration rate data, considering temperature-dependent deterioration rates. Pattnaik (2020) examines a real-life case study on the supply chain network design of premium milk in Odisha, addressing challenges associated with highly perishable products and emphasizing strategic decisionmaking at the network level. Nur et al. (2020) conduct a study to determine postharvest qualities at various storage temperatures and durations in perforated polyethylene, aiming to enhance the cooling chain in the mushroom industry and reduce postharvest losses. Xu et al. (2020) investigate the impact of carbon emissions on a deteriorating inventory system, proposing models for a continuous review inventory system with time-varying demand, shortages, and partial backlogging. They explore the existence and uniqueness of optimal solutions under carbon emission regulations. Pattnaik et al. (2021) introduce a milk supply chain network design challenge specific to the coastal region of Odisha. Their focus is on developing a comprehensive model multi-stage, multi-

product, multi-period supply chain network. In this model, they incorporate various strategic decision-making elements including order quantity, influence area, replenishment cycle time, preservation factor, replenishment cycle time and the number of proposed distribution centers for milk products. The author constructs a mixed-integer nonlinear programming (MINLP) model and performs sensitivity analysis to assess how alterations in model parameters affect the total profit of the supply chain network over

### 3. Top of Form Notations and Assumptions

The mathematical model is derived using the following notations and assumptions

#### 3.1. Assumptions

1. Time horizon is finite.
2. Demand rate is deterministic.
3. It is imperative to ensure that there are no instances of shortages.
4. The Deteriorating rate of blood item follows exponential distribution with temperature  $M_{Bi}$ ;  $\theta_{Bi} = \{\alpha_i e^{\beta M_{Bi}}, \text{ when } 2^\circ < M_{Bi} < 4^\circ\}$ .
5. Service regions exhibit irregular shapes rather than standardized geometrical shapes like circles, squares, or hexagons. Research has shown that the irregular shape of these areas has minimal impact on the optimum solution.
6. Each blood bank is located at the center of the service area and hospital is served by blood bank.
7. Optimal number of proposed blood bank in each cluster is  $B_i = \frac{it_{hh}}{influence\ service\ area\ area} = \frac{S}{AB_i}$  (*discrete*).
8. Each hospital is served by the blood bank.

### 3.2. Notations

$i$ : Number of clusters, $i= 1,2,3, \dots, N$ .
$B_i$ : Number of blood bank proposed.
$N$ : Number of index.
$I_i(t)$ : Inventory level for each blood bank in each cluster at time period $t$
$F_i$ : Facility cost of blood bank in each cluster.
$H_{Bi}$ : Inventory holding cost per unit item for each blood bank cluster.
$O_{Bi}$ : The outbound transportation cost per unit of distance for each item of blood bank supplies within each cluster.
$C_{Bi}$ : Unit purchasing cost of blood bank in each cluster.
$D_{Bi}$ : Total demand rate of blood bank in each cluster.
$\partial_{Bi}$ : Store density of blood bank in each cluster.
$F_{Br}$ : Constant that relies on the type of distance measurement and the configuration of the blood bank within the service area.
$T_B$ : Total cycle period for each blood bank.
$A_{Bi}$ : Influence area of blood bank in each cluster and $A_{Bi} > 0$ (decision variable).
$M_{Bi}$ : Storage temperature of blood bank in each cluster (decision variable).
$Q_{Bi}$ : Ordering quantity of blood bank in each cluster at the time period $(0, T_B)$ .
$\theta_{Bi}$ : Deteriorating rate of whole blood in each cluster where, $\theta_{Bi} = \{\alpha_i e^{\beta M_{Bi}}, 2^\circ < M_{Bi} < 4^\circ\}$

### 4. Objectives of the Study

The objective of this model is to

- To determine the optimal influence area
- To obtain the optimum total cycle time period
- To obtain optimum number of blood bank
- To obtain optimum storage temperature
- To obtain optimum order quantity
- To obtain total blood supply chain network design cost per unit time of whole blood for each cluster respectively and to explore how the optimal decision variables are influenced by variations in the major input variables.

### 5. Generic Mathematical Model

$Q_{Bi}$  represents the inventory level at the start of the cycle, which diminishes over time due to both demand and deterioration until it reaches zero at  $T_B$ . Shortages are not accumulated. The instantaneous inventory level at any time  $t$  in  $[0, T_B]$  is given by the following differential equation.

$$\frac{dI_i(t)}{dt} + \theta_{Bi} I_i(t) = -D_{Bi} S_{Bi} \partial_{Bi} \quad 0 \leq t \leq T_B \quad (1)$$

Given that,  $I_i(T_B) = 0$ .

The integrating factor (IF) =  $e^{\int \theta_{Bi} dt} = e^{\theta_{Bi} t}$  and incorporating this integrating factor into equation (1) through multiplication.

$$\frac{dI_i(t)}{dt} e^{\theta_{Bi} t} = -D_{Bi} S_{Bi} \theta_{Bi} e^{\theta_{Bi} t}$$

$$\Rightarrow \int dI_i(t) e^{\theta_{Bi} t} = -D_{Bi} S_{Bi} \theta_{Bi} \int e^{\theta_{Bi} t} dt.$$

$$I_i(t) = \frac{1}{\theta_{Bi}} \left[ -D_{Bi} S_{Bi} \theta_{Bi} e^{\theta_{Bi} t} + e^{\theta_{Bi} T_B} \right] e^{-\theta_{Bi} t} \quad (T_B - t) - 1$$

(3) The initial inventory level  $Q_{Bi}$  is obtained by putting  $t=0$  in equation (3)

$$Q_{Bi} = \frac{D_{Bi} S_{Bi} \theta_{Bi}}{\theta_{Bi}} (e^{\theta_{Bi} T_B} - 1)$$

### 5. 1. Model Components

$$\text{Total facility cost} = \sum_{i=1}^N F_{Bi} A_{Bi} S_{Bi} \theta_{Bi}$$

$$\text{Total inventory holding cost per unit item} = \sum_{i=1}^N H_{Bi} \int_0^{T_B} I_i(t) dt$$

$$\sum_{i=1}^N H_{Bi} D_{Bi} S_{Bi} \theta_{Bi} \frac{e^{\theta_{Bi} T_B}}{\theta_{Bi}} \left( \frac{C_{Bi} Q_{Bi}}{T_B} - T_B \right) = \frac{C_{Bi} D_{Bi} S_{Bi} \theta_{Bi} (e^{\theta_{Bi} T_B} - 1)}{T_B \theta_{Bi}} \sum_{i=1}^N \frac{\theta_{Bi}}{T_B} = \sum_{i=1}^N \frac{\theta_{Bi}}{T_B}$$

$$\text{Total purchasing cost per unit item} =$$

Presuming service regions that are ‘near circular’ with the facility situated at the centre, the average distance travelled by each item is  $F_{Br} \sqrt{A_{Bi}}$  (Dasci and Verter, 2001).

$$\text{Total outbound transportation cost} = \sum_{i=1}^N O_{Bi} F_{Br} \sqrt{A_{Bi}} D_{Bi} S_{Bi} \theta_{Bi}$$

$$\text{Total storage temperature cost} = \sum_{i=1}^N \beta M_{Bi}^2 D_{Bi} S_{Bi} \theta_{Bi}$$

Total blood supply chain network design cost per unit time = TFC+ THC+ TOTC+ TPC+ TSTC

$$TC_B = \sum_{i=1}^N \left[ F_{Bi} \frac{1}{\sqrt{A_{Bi}}} + \frac{H_{Bi} D_{Bi} S_{Bi} \theta_{Bi}}{A_{Bi}} \left( \frac{C_{Bi} Q_{Bi}}{T_B} - T_B \right) + \frac{C_{Bi} D_{Bi} S_{Bi} \theta_{Bi} (e^{\theta_{Bi} T_B} - 1)}{\theta_{Bi}} + \sqrt{\frac{\beta M_{Bi}^2 D_{Bi} S_{Bi} \theta_{Bi}}{T_B \theta_{Bi}}} O_{Bi} F_{Br} \right] \quad (4)$$

### 6. Optimization

The aim is to obtain, the optimal influence area for blood bank  $A_{Bi}$  cluster ‘i’, the optimal storage temperature  $M_{Bi}$ , the optimal cycle time period  $T_B^*$  and to minimize the total supply chain cost

$C_B(A_{B1}, A_{B2} \dots \dots \dots A_{BN}, |T_B, M_{Bi})$  and is a two branch function with  $N + 2$  decision variable. For given  $T_B$  and  $M_{Bi}$ . The derivative of  $C_B(A_{B1}, A_{B2} \dots \dots \dots A_{BN} | T_B, M_{Bi})$  with respect to  $A_{Bi}$  is given by:

$$\frac{\partial}{\partial A_{Bi}} C_B(A_{B1}, A_{B2} \dots \dots \dots A_{BN} | T_B, M_{Bi}) = -F_{Bi} \frac{1}{2\sqrt{A_{Bi}}} + C_{Br} F_{Br} 2 A_{Bi} D_{Bi} S_{Bi} \theta_{Bi}^{-1}$$

Now the second order derivative of  $C_B(A_{B1}, A_{B2} \dots \dots \dots A_{BN} | T_B, M_{Bi})$  with respect to  $A_{Bi}$  is given by

$$\frac{\partial^2 C_B(A_{B1}, A_{B2} \dots \dots \dots A_{BN} | T_B, M_{Bi})}{\partial A_{Bi}^2} = 2 F_{Bi} \frac{1}{4 A_{Bi}^{3/2}} - C_{Br} F_{Br} 4 A_{Bi} D_{Bi} S_{Bi} \theta_{Bi}^{-2}$$

$$\text{From } \frac{\partial C_B(A_{B1}, A_{B2} \dots \dots \dots A_{BN} | T_B, M_{Bi})}{\partial A_{Bi}}$$

$$\frac{\partial^2 C_B(A_{B1}, A_{B2} \dots \dots \dots A_{BN} | T_B, M_{Bi})}{\partial A_{Bi}^2}$$

= 0. It can get  $F_{Bi} = C_{Br}F_{Br}D_{2Bi}S_{Bi}^{\partial Bi}$ . This means

$$\frac{\partial^2 C_B(A_{B1}, A_{B2}, \dots, A_{BN} | T_B, M_{Bi})}{\partial A_{Bi}^2} > 0 \text{ when } F_{Bi} < \{C_{Br}F_{Br}D_{2Bi}S_{Bi}^{\partial Bi}\}$$

Since, the facility cost  $F_{Bi}$  is very Small.  $\frac{\partial^2 C_B(A_{B1}, A_{B2}, \dots, A_{BN} | T_B, M_{Bi})}{\partial A_{Bi}^2} > 0$  is satisfied in general case

$$\frac{\partial^2 C_B(A_{B1}, A_{B2}, \dots, A_{BN} | T_B, M_{Bi})}{\partial A_{Bi} M_{Bi}} \text{ and } \frac{\partial^2 C_B(A_{B1}, A_{B2}, \dots, A_{BN} | T_B, M_{Bi})}{\partial A_{Bi} A_j} = 0$$

$A_{Bi}$  is independent to  $A_j$ , where  $i = 1, 2, \dots, N$  and  $j = 1, 2, \dots, N$  and  $i \neq j$ . Now the Hessian Matrix is:

$$H_{N+1} = \begin{bmatrix} \frac{\partial^2 T C_B}{\partial A_{Bi}^2} & 0 & 0 \\ 0 & \frac{\partial^2 T C_B}{\partial M_{Bi}^2} & 0 \\ 0 & 0 & \frac{\partial^2 T C_B}{\partial T_B^2} \end{bmatrix} \quad (5)$$

Since  $\frac{\partial^2 C_B}{\partial A_{Bi}^2} > 0$  and  $\frac{\partial^2 C_B}{\partial M_{Bi}^2} > 0$ . From the Maximum theorem  $C_B(A_{B1}, A_{B2}, A_{B3}, A_{B4}, \dots, A_{BN} | T_B, M_{Bi})$  is a convex function of  $(A_{B1}, A_{B2}, A_{B3}, A_{B4}, \dots, A_{BN})$ . This means that the optimal  $A_{Bi}$ ,  $i = 1, 2, \dots, N$ , can be obtained by solving  $\frac{\partial C_B(A_{B1}, A_{B2}, A_{B3}, A_{B4}, \dots, A_{BN} | T_B, M_{Bi})}{\partial A_{Bi}} = 0$  which leads to

$$A_{Bi} = \sum_{i=1}^N \left( \frac{2F_{Bi}}{O_{Bi}F_{Br}D_{Bi}\partial Bi} \right)^{\frac{3}{2}} \quad (6)$$

## 7. Case Study

This study is based on a real-life case from the Blood Transfusion Organization of Odisha, which was established in 1996 under the National Blood Transfusion Council. As a critical component of the healthcare system, blood banks in Odisha are responsible for the testing, collection, preparation, and processing of blood and its components. This multifaceted process involves the careful selection of suitable products and transfusion protocols, guided by laboratory analysis and tailored to individual patient needs. It also includes the ongoing evaluation of transfusion effectiveness, which may vary depending on factors such as underlying health conditions, physiological status, or the type of medical intervention. Ensuring the highest standards of safety and ethics, the organization emphasizes voluntary, non-compensated blood donation from individuals who meet strict safety criteria, thereby reducing dependence on high-risk or unauthorized sources. To support and strengthen these efforts, the National AIDS Control Organization (NACO) has continuously worked to enhance blood bank infrastructure across India by providing essential equipment, skilled personnel, and capacity-building programs. In Odisha, particular focus has been placed on modernizing facilities, establishing innovative models, and setting up blood storage centers in rural areas to ensure accessible and high-quality transfusion services throughout the state. Odisha, located in eastern India, spans 155,707 km<sup>2</sup>—approximately 4.87% of the country's land area—and features a 450 km coastline. Geographically, the state is divided into two main regions: the Western region (130,569.21 km<sup>2</sup>) and the Coastal region (25,137.79 km<sup>2</sup>). A total of 83 blood banks operate within Odisha's blood bank networking system, with 18 situated in the Western region, including locations such as Sambalpur, Burla, Rairakhol, Kuchinda, Bargarh, Padmapur, Kantabanjhi, Titilagarh, Balangir, Jharsuguda, Deogarh, Dharmagarh,

Bhawanipatna, Boudh, Sonepur, Sundargarh, and Rourkela. For the purpose of this study, a focused analysis has been conducted on three districts from the Western region: Sambalpur, Bargarh, and Balangir—highlighting their role and potential in strengthening the healthcare delivery system in Odisha.

### 7.1. Results and Analysis.

The current model can be utilized to address the (SCND) of whole blood specifically in the western Odisha. The aforementioned scenario has implemented the suggested model, which was resolved using the Lingo 13.0 software package.

**Table 1:** Total Demand Rate of Blood Product (Whole Blood) in Western Odisha

Cluster (i)	Blood Bank	$S_{Bi}$ (Km) <sup>2</sup>	$D_{Bi}$ (Total Demand Rate) (ml.)
1	Sambalpur	6702	240
2	Bargarh	5837	60
3	Balangir	6575	70

**Table 2:** Dataset of the Whole Blood Product in Western Odisha

Parameters	Sambalpur	Bargarh	Balangir
$S_{Bi}$	6702	5837	6575
$D_{Bi}$	240	60	70
$\partial_{Bi}$	0.0121	0.0024	0.0091
$F_{Bi}$	82191.87	54794.52	80191.87
$H_{Bi}$	20	10	15
$O_{Bi}$	9	8	10
$C_{Bi}$	250	250	250
$F_{Br}$	0.2	0.2	0.2
$\alpha$	0.05	0.05	0.05
$\beta$	0.005	0.005	0.005

**Table 3: Optimal cost without shortage of whole blood in Odisha**

Cluster (i)	Blood Bank	Iteration	$S_{Bi}$	$A_{Bi}$	$B_i$	$Q_{Bi}$	$M_{Bi}(^{\circ})$	$T_B$	Cost (Rs.)	$C_B(\text{Rs.})$ (WOS)
1	Sambalpur	530	6702	957.4286	7	516788.5	4	5.948717	FC=870713.2	38820920.0
									HB=9038161	
2	Bargarh		5837	5837.000	1	22299.69	4		OTC=1578890	
							PC=27331200.0			
3	Balangir		6575	2191.668	3	111195.4	4	STC=1959.313		

Table 3 reveals the optimal value of the given model. It is investigated that the optimal solution of influence area of the cluster Sambalpur and Balangir and Bargarh are less than that service area. The optimal cycle time and the storage temperature are 5.948717 and 4degrees respectively. It was found that 3 blood banks are required in Sambalpur, 1 in Bargarh and 3 blood banks in Balangir clusters. The optimal order quantity is maximum for Sambalpur cluster whereas it is minimum for Balangir cluster. The optimal total SCND cost per unit item is Rs. 38820920.0 which has obtained after 530 iterations.

### 7.2. Comparative analysis

Table 4: Comparative Analysis

Case -I (Temperature Cost=0)										
Cluster(i)	Blood bank	Iteration	$S_{Bi}$	$A_{Bi}$	$B_i$	$Q_{Bi}$	$M_{Bi}(^{\circ})$	$T_B$	Costs (Rs)	$C_B$
1	Sambalpur	521	6720	957.4286	7	516788.5	4	5.948717	FC=870713.2	38818960.0
									HC=9038161	
2	Bargarh		5837	5837.000	1	22299.69	4		OTC=1578890	
							PC=27331200.0			
3	Bolangir		6575	2191.668	3	111195.4	4			
Case-II $M_{Bi}= 3/3/3$										
Cluster	Blood Bank	Iteration	$S_{Bi}$	$A_{Bi}$	$B_i$	$Q_{Bi}$	$M_{Bi}(^{\circ})$	$T_B$	Costs (Rs)	$C_B$
1	Sambalpur		6720.000	957.4286	7	518900.9	3		FC=870713.2	

2	Bargarh	468	5837.000	5837.000	1	223900.83	3	5.960395	HC=9070775	38910610.0
3	Bolangir		6575.000	2191.668	3	111649.9	3		OTC=1578890	
									PC=27389150.0	
									STC=1102.113	
Case-III $M_{Bi}= 2/2/2$										
Cluster	Blood bank	Iteration	$S_{Bi}$	$A_{Bi}$	$B_i$	$Q_{Bi}$	$M_{Bi}(^{\circ})$	$T_B$	Costs (Rs)	$C_B$
1	Sambalpur	446	6720.000	952.4286	7	521023.2	2	5.972088	FC=870713.2	39000870.0
2	Bargarh		5837.000	5837.000	1	22482.39	2		HC=9103450	
									OTC=1578890	
									PC=27447320.0	
									STC=489.8282	
3	Balangir		6575.000	2191.668	3	112106.6	2			

Table 4 indicates the comparative analysis of BSCND model. Three cases are analysed in above table. The cases are such that (Total Temperature Cost=0 and Storage temperature  $M_{Bi}=3/3/3$ ,  $M_{Bi}=2/2/2$ ). It is found the optimum influence area of the cluster Sambalpur and Bolangir and Bargarh are less than their service areas. The optimum number of blood bank is same for three clusters under three cases. Under the case-I the optimal order quantity of whole blood is maximum whereas it is minimum for cluster Balangir. Under case-II the optimal order quantity is maximum for Sambalpur cluster and minimum for Bolangir cluster. Similarly, under case-III the optimal order quantity of whole blood is maximum for sambalpur cluster whereas is minimum for cluster Balangir. Taking into account the above comparative analysis reveals about the optimal order quantity is maximum for cluster Sambalpur cluster and minimum for Bolangir cluster under the three cases. The optimal storage temperature is also same for three clusters under three cases. The optimum cycle time under case I is 5.948717, under case II is 5.960395 and under case-III is 5.972088 respectively. However the optimal cycle time is maximum under the case-III. The optimum total supply chain cost per unit item under case-I is Rs. 38818960.0, under case-II is Rs. 38910610.0 and under case III is Rs. 39000870.0 respectively. It is maximum for case III. The incoming analysis shows that the inventory quantities decrease since the inaccuracy of temperature control, therefore the optimal temperature controls the maximum inventory it has. The energy of temperature plays a strategic role along the blood banks. So that it is an effective and essential for the blood quality maintenance. Figures 7, 8 and 9 show the plotting of all existing blood banks of three clusters

of western regions of Odisha. Figure 11, 12 and 13 depicts the plotting of all proposed blood banks of three clusters. Figure 14, 15 and 16 shows the plotting of both existing and proposed blood banks of three clusters. Figure 17 shows all the existing and proposed blood banks of three clusters.

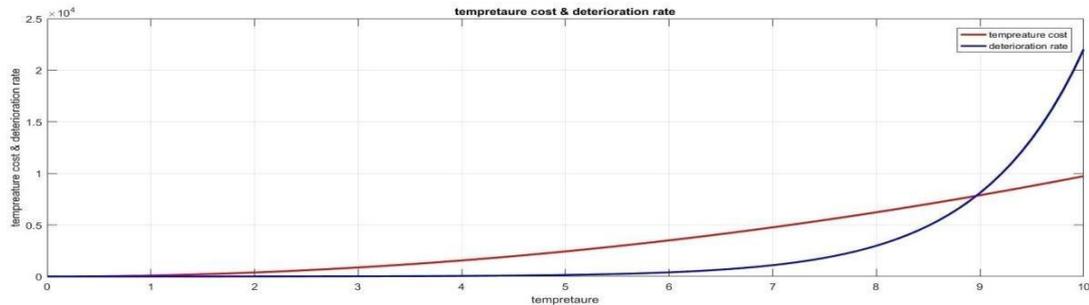


Figure 7. 2D plotting of temperature with temperature cost and deterioration rate

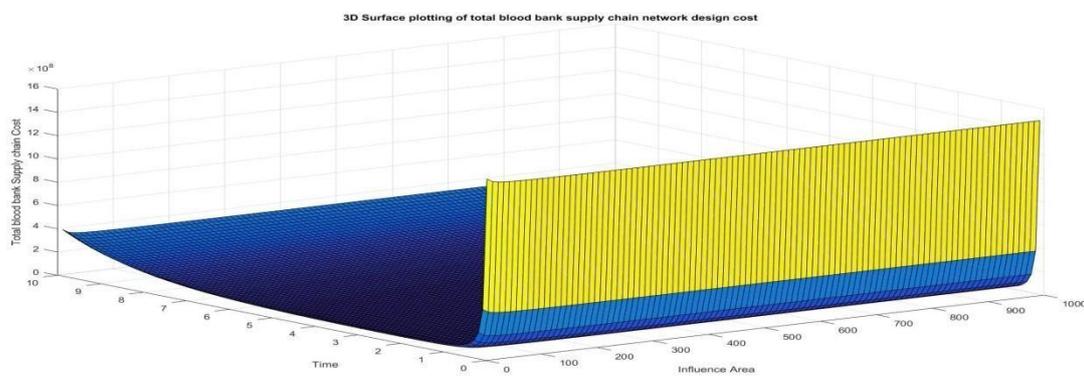


Figure 8. 3D Surface plotting of Blood Bank Supply Chain Network Design Cost

### 7.3.Sensitive Analysis

A sensitivity analysis of the optimal solution in BSCND model is obtained by changing in the input variables. The sensitivity results of this model are summarized in Table 5

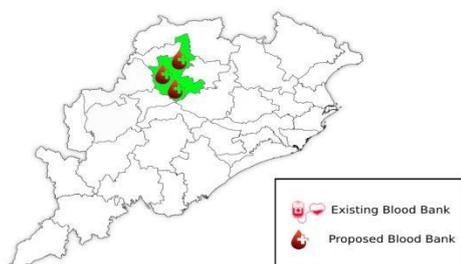


Figure 12: Proposed Blood Bank in Sambalpur.

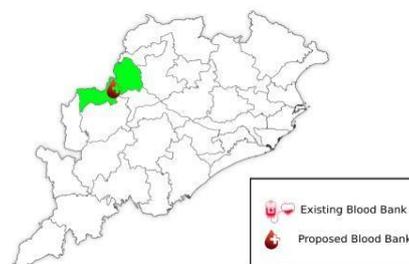


Figure 13: Proposed Blood Bank in Bargarh



Figure 14: Proposed Blood Bank in Balangir.

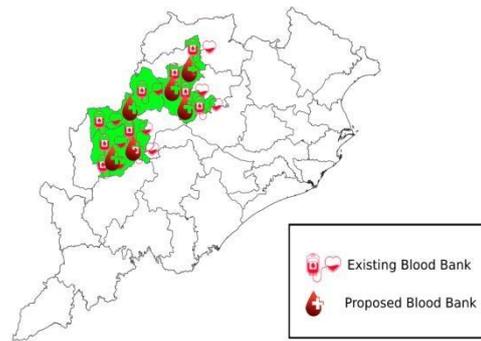


Figure-19: Both Existing and Proposed Blood Banks

**Table 6:** Summary of Sensitive Analysis

Variable	$A_{Bi}^*$	$M_{Bi}^*$	$Q_{Bi}^*$	$T_{B^*}$	$C_{B^*}$
$F_{Bi}$	IS	IS	IS	IS	IS
$H_{Bi}$	HS	IS	MS	MS	MS
$O_{Bi}$	HS	IS	HS	IS	MS
$C_{Bi}$	HS	IS	MS	MS	MS
$D_{Bi}$	HS	IS	MS	MS	MS
$F_{Br}$	HS	IS	IS	IS	MS
$S_{Bi}$	HS	IS	MS	MS	MS
$\beta$	HS	IS	MS	MS	MS
$\alpha_i$	HS	IS	HS	MS	MS

Note: HS-Highly Sensitive, IS- Insensitive, MS-Moderate Sensitive.

It is noticed from Table 5 (Appendix 5) and Table 6 that the optimal influence area for the blood banks is highly sensitive towards the variables namely holding cost, outbound transportation cost, unit purchasing cost, service area, demand, the density constant,  $\alpha_i$  and  $\beta$ . Similarly, Optimal order quantity are sensitive in high level towards the outbound transportation cost,  $\beta$ . Optimal order quantity, total time period, and total BSCND cost per unit item is moderate sensitive towards the variables i.e.  $H_{Bi}, O_{Bi}, C_{Bi}, D_{Bi}, F_{Br}, S_{Bi}, \alpha_i, \beta$ . In the same way optimal influence area, optimal order quantity, total cycle time period and total BSCND cost per unit item is insensitive towards the variable viz.  $F_{Bi}, F_{Br}$  and storage temperature is insensitive for all input variables. Taking into consideration, the blood bank should be careful to 8 major input variables like  $H_{Bi}, O_{Bi}, C_{Bi}, D_{Bi}, F_{Br}, S_{Bi}, \alpha_i, \beta$  of whole blood product to disregard the issue of sensitivity in the total BSCND cost per unit item.

## 8. Conclusions

This study examined (SCND) model for whole blood in the western Odisha, taking into account inventory deterioration and storage temperature. The suggested model incorporates holding cost, outbound transportation cost, facility cost, purchasing cost, and temperature-related expenses. The key findings lead to obtain of the optimum influence area, total cycle time period, and temperature to minimize the total supply chain cost per unit time. In addition to, optimum number of proposed blood bank and optimum order quantity in each cluster are also

evaluated. A piecewise mixed integer nonlinear optimization method is provided to solve BSCND problem accurately. The present model is justified through numerical analysis on real-life case study data. In western Odisha, ten no. of clusters such as Boudh, Deogarh, Sambalpur, Bargarh, Subarnapur, Bolangir, Nuapada, Jharsuguda, Kalahandi, and Sundargarh. Due to the pandemic situation three districts is considered for this study named as Sambalpur, Baragr, and Bolangir. Currently, there is only one Blood Bank in each of the three clusters, which is insufficient based on the required demand rate. The analysis reveals that the total supply chain cost per unit time is Rs. 38,820,920.0, derived after 530 iterations. The findings suggest that maintaining the appropriate temperature of whole blood products helps to reduce the total supply chain cost per unit. Additionally, it is observed that the optimal influence area for Sambalpur and Bolangir is smaller than their respective service areas, while for the Bargarh cluster, it remains the same. Therefore, the optimal number of blood banks for the three clusters, namely Sambalpur, Bargarh, and Bolangir, are determined to be 7, 1, and 3 respectively. Initially, there were 3 existing blood banks in these clusters. However, upon achieving the optimal solution, an additional 8 proposed blood banks are suggested, making the total count of blood banks in these clusters to be  $8+3=11$ . The optimal order quantity of whole blood is maximum in Sambalpur cluster whereas it is minimum in Bolangir cluster. Additionally, the optimal storage temperature and total cycle period are determined to be 4 degrees and 5.9448717 days, respectively. Furthermore, a sensitivity analysis has been conducted to assess the impact of major input variables on decision variables and the total supply chain network design cost. More research in this area could be done to develop the exciting opportunities for transformative advancements in healthcare systems. Leveraging cutting-edge technologies such as artificial intelligence, predictive analytics, and block chain, researchers can optimize the spatial and temporal aspects of blood camp locations, ensuring a responsive and adaptive network that caters to dynamic population needs. Integration of mobile health units equipped with advanced medical technologies and the implementation of innovative community engagement strategies hold promise in reaching underserved areas and bolstering donor participation. However, despite these prospects, several challenges persist.

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