Annals of Emerging Technologies in Computing (AETiC)
Vol. 10, No. 3, 2026

Research Article

Real-World Application of a Stochastic Three-Objective Optimization Model for Greening, Cost Reduction, and Time Management in a Blood Supply Chain Network: A Case Study

Xu Guo

College of Electronics and Information, Shanghai Dianji University, Shanghai 201306, China
guox@sdju.edu.cn

Received: 10th March 2025; Accepted: 25 June 2026; Published: 1 July 2026

Abstract: Managing a green Blood Supply Chain (BSC) under stochastic demand and perishability constraints presents a critical optimization challenge. This study addresses this by proposing a novel four-echelon, multi-objective Mixed Integer Programming (MIP) model designed to minimize network costs, transportation time, and environmental impacts (waste and emissions) simultaneously. Unlike previous deterministic models, this research incorporates stochastic demand utilizing a chance-constrained programming approach and explicitly models the shelf-life constraints of three distinct blood products (red blood cells, platelets, plasma). To handle the conflicting objectives, the Lp-metric method converts the multi-objective model into a single-objective formulation, enabling efficient solution via the CPLEX solver in GAMS. The model's applicability is validated through a numerical case study, followed by a comprehensive sensitivity analysis on waste ratios and demand fluctuations. Results demonstrate that the proposed framework effectively balances cost-efficiency with sustainability, reducing waste by optimizing flow allocations. Furthermore, the study discusses the computational trade-offs between exact methods and heuristic approaches for large-scale implementations. This research bridges the gap between theoretical green logistics and practical healthcare supply chain management, offering a robust decision-support tool for blood center managers to navigate uncertainties in demand and product shelf-life.

Keywords: ***Blood Supply Chain; Green Logistics; Lp-metric; Shelf Life; Stochastic Optimization***

---

1. Introduction

A supply chain network design (SCND) is a sophisticated system for controlling the flow of products, data, and cash across different businesses [1,2]. SCND is now the most important area of study in SC management. Numerous studies on this issue have previously been conducted [3,4]. One of the main problems with SCN is its complexity, especially when the distinctive features of perishable products are considered, or demand is uncertain [5-7]. A significant part of people's health can have a profound impact on people's functioning and living. Studies in this still brand-new and worth-investigating field have been increasing in recent years, demonstrating the importance of healthcare management. In recent years, Blood Supply Chains (BSC) have been one of the most intriguing topics in the healthcare systems literature. Blood is a necessary resource for people's health and well-being, making it an extraordinary commodity. Unlike business SCs, which focus on profit maximization, BSC focuses on service provision. Blood is a scarce product and can only be produced voluntarily by blood donors. Three different forms of blood products, including red blood cells, platelets, and plasma, may be made from a single unit of donated blood.

Xu Guo, "Real-World Application of a Stochastic Three-Objective Optimization Model for Greening, Cost Reduction, and Time Management in a Blood Supply Chain Network: A Case Study", *Annals of Emerging Technologies in Computing (AETiC)*, Print ISSN: 2516-0281, Online ISSN: 2516-029X, 1 July 2026, Vol. 10, No. 3, pp. 16-31, Published by International Association for Educators and Researchers (IAER), DOI: 10.33166/AETiC.2026.03.002, Available: http://aetic.theiaer.org/archive/v10/v10n3/p2.html.

Moreover, blood products are perishable, and the lack of these products can directly affect human lives by increasing the mortality rate. Patients with an urgent need for blood products are customers of the blood SC, and the fact that the process of production is done voluntarily by donors makes BSC more complex than other SCs [8,9]. In high-pressure healthcare environments, systemic inefficiencies can overwhelm staff (similar to the phenomenon of 'alarm fatigue' observed in clinical settings [10]) thereby compromising patient safety. Several steps in SC deliver a unit of blood to the patients. The first one is blood collection from donors (suppliers), which succeeded by evaluating and producing blood products in laboratories. The products are then delivered to hospitals and patients. However, various research papers have investigated multi-echelon SCs instead of two-echelon.

A major challenge that BSC managers face is when the blood products market demand increases while the count of donors diminishes. Moreover, the expenses of testing, production, transportation, storage, and distribution are also challenging for managers. Therefore, BSC officials need to meet the demands, reduce waste, and minimize expenses. With all that said, what makes the BSC even more sophisticated is the perishability of the blood products, which increases the count of constraints and expenses of the system. As a result, a numerical scheme would be suitable for the situation and can help achieve diverse objectives, ranging from minimizing expenses to maximizing reliability or reducing CO_2 emissions in a green SC [11].

Like conventional SCs, the establishing expenses of a BSC are fundamental. On the other hand, blood is vital for patients in need of it. Therefore, blood products must be delivered to the hospitals as soon as possible. Furthermore, there is the possibility of generating waste in the process because of blood corruption or contamination. Upon conducting the literature review, we concluded that no previous research works have simultaneously examined BSC expenses, transportation time, and environmental impacts of the SC as the objectives while including shelf lives, stochastic demand, and three blood products into the scheme. Considering this, this investigation is to lower system expenses, transportation time, and detrimental environmental impacts.

2. Literature Review

Optimization of Blood Supply Chains (BSC) has developed considerably over the last decades and ceased being a deterministic cost-minimization model and became a complex stochastic model that focuses on sustainability and resilience. This section will synthesize the literature that is available to date into three main streams: Deterministic vs. Stochastic approaches, Green Supply Chain evolution, and the recent shift towards Resilience of the post-COVID-19 era.

2.1. Deterministic and Stochastic Models

Experimental studies were mainly directed towards deterministic models. The foundations were made by Or and Pierskalla [12] with the location-allocation and integer programming to minimize costs. These models, however, could not explain the fluctuations in demand inherent in healthcare. To solve this, Salehi *et al*. [13] and Osorio *et al*. [11] proposed strong stochastic programming on the basis that deterministic models generate stockouts in response to peaked demand. Although robust optimization can deal with worst-case scenarios, Dillon *et al*. [14] observed that it tends to provide solutions that are too conservative, indicating that chance-constrained programming, as applied in this study, can provide a more balanced solution between reliability and cost.

2.2. Green Logistics and Compatibility with Contradictory Objectives

BSC incorporation of environmental issues is a relatively recent phenomenon. One of the earliest models of Green BSCs was made by Heidari-Fathian and Pasandideh [15], who addressed the reduction of CO_2 emissions. One of the debates that is critical in this field is the tradeoff between Greening and Speed. Eskandari-Khanghahi *et al*. [16] pointed out that the accelerated ways of transportation (which are necessary when using perishable blood) tend to produce more emissions, which is incompatible with the objectives of sustainability. In contrast to commercial supply chains, where profit is the key factor, Khalilpourazari and Arshadi Khamseh [17] claimed that in BSCs, the loss of the expired blood is a twofold burden: it is an economic loss and a risky environmental waste. In our work, we develop our work based on this principle by modeling explicit waste minimization as a fundamental environmental goal, not just simple transport emissions.

2.3. Current Development: Resilience and Technology (2020-2025)

Since 2020, there has been a shift to resilience, and it is a paradigm shift due to the COVID-19 pandemic disruptions. Ameri *et al*. [18] highlighted the critical role of health literacy and preventive behaviours during the pandemic, underscoring the need for resilient systems that can adapt to public health crises. As was shown in Li *et al*. [19], the lateral transshipment policies enhance the resilience to regional shortages by a considerable margin. In addition, the deployment of Industry 4.0 has become more popular; Belgada & El Abbadi [20] investigated the way in which IoT and Blockchain can be utilized to establish better real-time traceability, which would immediately decrease the age of blood when it is delivered. Also, Mohamed & Huynh [21] used deep learning to forecast demand to overcome the so-called bullwhip effect when ordering blood. In spite of these technological advances, an existing gap in mathematical modeling that is capable of measuring the synergy between the management of shelf life and carbon footprint reduction in stochastic constraints without pure simulation still exists. The present research is an attempt to fill this particular gap in the methodology.

2.4. Novelty and Contribution of the Proposed Methodology

The study develops a new mathematical model which is formulated on stochastic mixed integer programming with chance constrained programing. The presented model is a step towards improvement of deterministic approaches which did not consider stochasticity of demands and perishable characteristic of more than one type of blood product including red blood cells, platelets and plasma. While similar approaches to MIP and chance constrained programs have been used independently, the combination of four echelons and multi-objective optimization in the blood supply chain is what makes the presented model distinctive. It enables obtaining results related to cost reduction and sustainability of the blood supply chain.

The novelty of the research is related not only to the methodology used but also to the applicability of the developed approach. The problem addressed in the article has gained relatively little attention in literature on blood supply chains because of complexity of the system, its dynamics, and uncertainty inherent to it. In addition, the efficiency of the proposed model is proved by means of numerical experiments and sensitivity analysis that demonstrates the possibility of minimizing costs and wastes.

Thus, while the research uses proven approaches, the use of stochasticity to achieve sustainability of the network is what creates the novelty in optimization theory.

3. Model Definition

3.1. Problem Description

The BSC under investigation is composed of 4 echelons as depicted in Figure 1: blood-collecting centers where blood is donated, laboratories where blood units from collecting centers are tested, main blood centers where tested blood units produce three blood products of plasma, red blood cells, platelets, and hospitals that make up the demand points. Blood groups, blood products, and expiration dates are considered in this investigation.

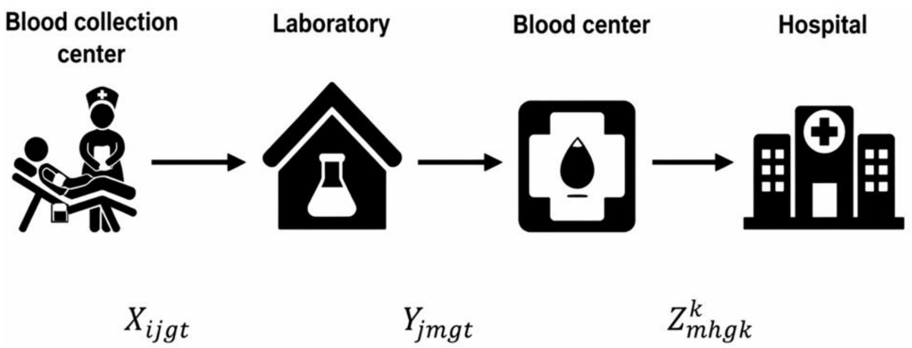

Figure 1. Graphical representation of BSC

The location of blood-collecting centers is fixed, but if one will be established in a period is of question. Blood can only be donated in the blood-collecting centers, and blood units are then shipped to the laboratories where the required tests are executed. In the next step, tested blood units will be transported to the main blood centers where three blood products will be produced to be sent to the demand points. The blood demands of each blood product in hospitals will be fulfilled by the key blood centers.

The scheme is a three-purpose MIP: The first objective function minimizes the SC expenses, which comprise operational, holding, establishment, and transportation expenses. The second objective function tries to lower blood transportation time between collecting centers, laboratories, main blood centers, and hospitals. The third objective function is dedicated to the minimization of environmental impacts of the network. Carbon emissions and wastes in each center are the environmental impacts the third objective function tries to lower. The scheme wants to determine the subsequent decisions at each period:

- The quantity of each blood group was collected from the collecting center and transported to other centers
- The inventory level of the hospitals from each blood group and blood product
- Whether or not centers should be established based on the expenses of the establishment
- The nodes to transport blood units between centers based on transportation expenses, time, and environmental impacts

3.2. Model Assumptions

- All centers have limited capacities for receiving and storing blood products.
- Three blood products are produced at the main blood centers: red blood cells, plasma, and platelets.
- A shelf life is ascribed to each of the three blood products.
- A percentage of the waste is assigned to each center (except the collecting center) due to the diseases and medical considerations that might detect the blood units to be unusable.
- The operational, transportation, and establishment expenses of the network are deterministic and stable.
- The transportation and operation times are considered deterministic and fixed. This assumption is grounded in the tactical nature of the proposed model, where standard delivery routes and scheduled laboratory procedures follow strict protocols with minimal variance under normal operating conditions.
- The blood demand is stochastic, with a normal distribution.
- All collected blood units will be transported to the labs, key blood centers, and hospitals, respectively.
- None of the collecting centers, labs, or main blood centers keeps inventories. Inventories are only kept in hospitals.

4. Mathematical Model

According to the above description and assumptions of the issue, a numerical scheme of an SC network is presented in detail. Also, a nomenclature table is provided in Table 1.

Table 1. Nomenclature of sets, indices, parameters, and decision variables for the proposed model

Sets and Indices	
Blood collection center	$I = (i, ib)$
Lab	$J = (j, jb)$
Main blood center	$M = (m, mb)$
Hospital	$H = (h, hb)$
Blood products	$K = (k, kb)$
Blood groups	$G = (g, gb)$
Parameters	
M	a big enough number
a_i	operation time for each blood unit at the blood collection center i
a_j	laboratory operation duration for each blood unit (j)
a_m	operation time at the blood center m for each blood unit
a_h	operation time at the hospital h for each blood unit
d_{ij}	distance between collection center i to lab j
d_{jm}	distance between lab j to blood center m

d_{mh}	distance between blood center m to hospital h
ot_i	overall operation duration at the collection center i
ot_j	overall operation duration at the lab j
ot_m	overall operation duration at the blood center m
ot_h	overall operation duration at the hospital h
d_{hgt}^k	blood demand of hospital h in period t for blood group g and blood product k
cc_{igt}	operation cost of collection center i from group g at period t
cl_{jgt}	operation expense of lab j from group g at period t
cb_{mgt}	operation cost of blood center m from group g at period t
h_{hgt}	holding cost of one unit of blood group g in hospital h, at period t
ec_i	configuration expense of blood collection center i
el_j	configuration expense of lab j
eb_m	configuration expense of blood center m
eh_h	configuration expense of hospital h
trl_{ij}	transportation cost from collection center i to lab j per unit distance
trm_{jm}	transportation cost from lab j to blood center m per unit distance
trh_{mh}	transportation expense from blood center m to hospital h per unit distance
tti_{ij}	transportation time between blood collection center i & lab j
ttj_{jm}	transportation time between lab j & blood center m
ttm_{mh}	transportation time between blood center m & hospital h
$envc_{ij}$	environmental impacts of travel from collection center i to lab j per unit distance
$envl_{jm}$	environmental impacts of travel from lab j to blood center m per unit distance
$envb_{mh}$	environmental impacts of travel from blood center m to hospital h per unit distance
p_j	waste ratio of lab j
p_m	waste ratio of main blood center m
p_h	waste percentage of hospital m
cap_{igt}	capacity of blood collection center i from blood group g in period t
cap_{jgt}	capacity of lab j from blood group g in period t
cap_{mgt}	capacity of blood center m from blood group g in period t
cap_{hgt}	capacity hospital h from blood group g in period t
$exdate_{gmax}^k$	maximum time a unit of product k from group g can be used (expiration time)
Variables	
X_{ijgt}	quantity of blood group g in blood collection center i to be sent to lab j in period t
Y_{jmgt}	quantity of blood group g in lab j to be sent to blood center m in period t
Z_{mhgt}^k	quantity of blood product k from group g produced in blood center m to be sent to hospital h in period t
inv_{hgt}^k	inventory of blood product k from group g at hospital h in period t
wc_i	Binary; equals 1 if a collection center is configured at node i, equals 0 o.w
wl_j	Binary; equals 1 if a lab is established at node j, equals 0 o.w
wb_m	Binary; equals 1 if a blood center is established at node m, equals 0 o.w
wh_h	binary; equals 1 if a hospital is configured at node h, equals 0 o.w
q_{ij}	Binary; equals 1 if the arc between collection center i and lab j is deployed equals 0 o.w
q_{jm}	Binary; equals 1 if the arc between lab j and blood center m is used, equals 0 o.w
q_{mh}	binary; equals 1 if the arc between blood center m and hospital h is used, equals 0 o.w
WP_t	amount of waste in period t

I. Objective Functions

$$\min Z_1 = \sum_i \sum_j \sum_g \sum_t cc_{igt} \times X_{ijgt} + \sum_j \sum_m \sum_g \sum_t cl_{jgt} \times Y_{jmgt} + \sum_k \sum_m \sum_h \sum_g \sum_t cb_{mgt} \times Z_{mhgt}^k$$
$$+ \sum_k \sum_h \sum_g \sum_t h_{hgt} \times inv_{hgt}^k + \sum_i ec_i \times wc_i + \sum_j el_j \times wl_j + \sum_m eb_m \times wb_m + \sum_h eh_h \times wh_h$$
$$+ \sum_i \sum_j trl_{ij} \times q_{ij} \times d_{ij} + \sum_j \sum_m trm_{jm} \times q_{jm} \times d_{jm} + \sum_m \sum_h trh_{mh} \times q_{mh} \times d_{mh}$$

$$\min Z_2 = \sum_i \sum_j tti_{ij} \times q_{ij} + \sum_j \sum_m ttj_{jm} \times q_{jm} + \sum_m \sum_h ttm_{mh} \times q_{mh}$$

$$\min Z_3 = \sum_i \sum_j envc_{ij} \times q_{ij} \times d_{ij} + \sum_j \sum_m envl_{jm} \times q_{jm} \times d_{jm} + \sum_m \sum_h envb_{mh} \times q_{mh} \times d_{mh}$$
$$+ \sum_j \sum_m \sum_g \sum_t p_j \times Y_{jmgt} + \sum_m \sum_h \sum_g \sum_k \sum_t p_m \times Z_{mhgt}^k + \sum_h \sum_g \sum_k \sum_t p_h \times inv_{hgt}^k$$

II. Model Constraints

$$\sum_{k}\sum_{m} Z^{k}_{mhgt} - WP_t - inv^{k}_{hgt} + inv^{k}_{hgt-1} = \sum_{k} d^{k}_{hgt} \qquad \forall h, g, t \qquad (1)$$

$$\sum_{j} X_{ijgt} \leq cap_{igt} \times wc_i \qquad \forall i, g, t \qquad (2)$$

$$\sum_{m} Y_{jmgt} \leq cap_{jgt} \times wl_j \qquad \forall j, g, t \qquad (3)$$

$$\sum_{k}\sum_{h} Z^{k}_{mhgt} \leq cap_{mgt} \times wb_m \qquad \forall\, m, g, t \qquad (4)$$

$$\sum_{k}\sum_{m} Z^{k}_{mhgt} \leq cap_{hgt} \times wh_h \qquad \forall\, h, g, t \qquad (5)$$

$$\sum_{i} X_{ijgt} \geq \sum_{m} Y_{jmgt} \qquad \forall j, g, t \qquad (6)$$

$$\sum_{j} Y_{jmgt} \geq \sum_{k}\sum_{h} Z^{k}_{mhgt} \qquad \forall m, g, t \qquad (7)$$

$$\sum_{m} Z^{k}_{mhgt} \geq d^{k}_{hgt} \qquad \forall k, h, g, t \qquad (8)$$

$$\begin{aligned} &(tti_{ij} \times q_{ij}) + (ttj_{jm} \times q_{jm}) + \sum_{m}(ttm_{mh} \times q_{mh}) + (ot_i \times wc_i) \\ &+ (ot_j \times wl_j) \\ &+ \sum_{m}(ot_m \times wb_m) + (ot_h \times wh_h) \leq \sum_{k}\sum_{g} exdate^{k}_{gmax} \end{aligned} \qquad \forall i, j, h \qquad (9)$$

$$a_i \times \sum_{j}\sum_{g}\sum_{t} X_{ijgt} \leq ot_i \qquad \forall i \qquad (10)$$

$$a_j \times \sum_{m}\sum_{g}\sum_{t} Y_{jmgt} \leq ot_j \qquad \forall j \qquad (11)$$

$$a_m \times \sum_{h}\sum_{g}\sum_{t}\sum_{k} Z^{k}_{mhgt} \leq ot_m \qquad \forall m \qquad (12)$$

$$a_h \times \sum_{k}\sum_{g}\sum_{t} d^{k}_{hgt} \leq ot_h \qquad \forall h \qquad (13)$$

$$\sum_{g}\sum_{t} X_{ijgt} \leq M \times q_{ij} \qquad \forall i, j \qquad (14)$$

$$\sum_{g}\sum_{t} Y_{jmgt} \leq M \times q_{jm} \qquad \forall j, m \qquad (15)$$

$$\sum_{k}\sum_{g}\sum_{t} Z^{k}_{mhgt} \leq M \times q_{mh} \qquad \forall m, h \qquad (16)$$

$$\sum_{g}\sum_{t} X_{ijgt} \geq M \times (1 - q_{ij}) \qquad \forall i, j \qquad (17)$$

$$\sum_{g}\sum_{t} Y_{jmgt} \geq M \times (1 - q_{jm}) \qquad \forall j, m \qquad (18)$$

$$\sum_{k}\sum_{g}\sum_{t} Z^{k}_{mhgt} \geq M \times (1 - q_{mh}) \qquad \forall m, h \qquad (19)$$

$$\begin{aligned} WP_t = &\sum_{j}\sum_{m}\sum_{g} p_j \times Y_{jmgt} + \sum_{m}\sum_{h}\sum_{g} p_m \times Z^{k}_{mhgt} \\ &+ \sum_{h}\sum_{g} p_h \times inv^{k}_{hgt} \end{aligned} \qquad \forall k, t \qquad (20)$$

$$X_{ijgt},,\ Y_{jmgt},,\quad Z^{k}_{mhgt},,\quad WP_t \geq 0 \qquad \forall \text{i, j, m, h, t} \tag{21}$$

$$q_{ij},,,q_{jm},,,q_{mh},,,wc_i,,,wl_j,,,wb_m,,,wh_h \in \{0,1\} \qquad \forall \text{i, j, m, h} \tag{22}$$

The first function tries to lower the overall expenses of the SC, including operation, establishment, inventory holding, and transportation expenses. The second function tries to lower the travel time between network centers. In the third function, the environmental impacts of the network, including carbon emissions and waste from the centers, are minimized. Constraint (1) ensures that the demands of hospitals are met. Constraints (2) to (5) are capacity constraints for blood-collecting centers, labs, main blood centers, and hospitals. Constraints (6) and (7) make sure the incoming amounts of blood to the next center are not greater than the amounts of blood sent from the latter. Constraint (8) sets the maximum allowed time for blood product consumption based on their shelf lives. Constraints (9) to (12) relate to the operation time in each center and point, which should not be more than a certain limit. Constraints (13) to (18) manage the activation of transportation arcs between nodes. Constraint (19) calculates the total waste generated in each center based on the waste ratios. Constraint (20) ensures the non-negativity of all continuous decision variables (quantities and inventory levels). Finally, Constraints (21) and (22) enforce the binary nature of the decision variables related to facility establishment and arc selection, respectively.

4.1. Stochastic Parameter

Since the demand parameter d_{hgt} follows a Normal distribution with mean μ_{hgt} and standard deviation $\sigma_{hgt}\left(d_{hgt} \sim N(\mu_{hgt}, \sigma^2_{hgt})\right)$, the stochastic demand constraint can be reformulated via **Chance-Constrained Programming (CCP)** to obtain a deterministic equivalent.

Probabilistic Formulation

The demand satisfaction constraint is required to hold with a reliability level α(e.g., $\alpha = 0.95$):

$$P(\text{Supply} \geq d_{hgt}) \geq \alpha \tag{23}$$

This ensures that the available supply meets or exceeds uncertain demand with probability at least α.

Standardization

Because d_{hgt} is normally distributed, define the standardized variable:

$$P(Z = \frac{d_{hgt} - \mu_{hgt}}{\sigma_{hgt}} \sim N(0,1) \tag{24}$$

Then,

$$P(\text{Supply} \geq d_{hgt}) = P\left(\frac{d_{hgt} - \mu_{hgt}}{\sigma_{hgt}} \leq \frac{\text{Supply} - \mu_{hgt}}{\sigma_{hgt}}\right) \tag{25}$$

Using the cumulative distribution function (CDF) of the standard normal distribution, $\Phi(\cdot)$:

$$\Phi\left(\frac{\text{Supply} - \mu_{hgt}}{\sigma_{hgt}}\right) \geq \alpha \tag{26}$$

Deterministic Equivalent

Applying the inverse standard normal CDF:

$$\frac{\text{Supply} - \mu_{hgt}}{\sigma_{hgt}} \geq \Phi^{-1}(\alpha) = Z_\alpha \tag{27}$$

Rearranging yields the linear deterministic constraint:

$$\text{Supply} \geq \mu_{hgt} + Z_\alpha \sigma_{hgt} \tag{28}$$

Define the deterministic demand upper bound as:

$$\hat{d}_{hgt} = \mu_{hgt} + Z_\alpha \sigma_{hgt} \tag{29}$$

Interpretation in the MIP Model

In the final Mixed-Integer Programming (MIP) formulation, the stochastic demand parameter d_{hgt} is replaced by $\hat{d}_{hgt}$.

This term consists of:

- The **expected demand** μ_{hgt}, and
- A **safety stock component** $Z_\alpha \sigma_{hgt}$, which ensures the desired service level α.

For instance, if $\alpha = 0.95$, then $Z_{0.95} \approx 1.645$, meaning the model protects against demand realizations up to the 95th percentile of the distribution.

Thus, CCP enables the incorporation of stochastic demand uncertainty into a linear deterministic framework while preserving tractability and guaranteeing a predefined reliability level.

5. Numerical Examples

5.1. Computational Experiments

The availability of full, real-time information about a particular blood supply network in a healthcare system is limited by the stringent privacy laws (including HIPAA) and the confidentiality of operational data. Thus, to confirm the quality and the soundness of the proposed model, we used a simulated dataset that was developed on the basis of the realistic parameters that are found in the literature. This will enable a detailed sensitivity analysis to be conducted on a broader set of conditions than would be possible on a single static dataset. To evaluate the recommended scheme's performance, the scheme is solved as a problem of small size with an exact approach. GAMS is used to resolve small issues because GAMS is a modeling language that quickly translates optimization problems into computer codes. Once the code has been written, the GAMS compiler converts it into a format that the solvers can read and execute. As the design is adaptable to different solvers, it allows for a wide range of modeling possibilities to be explored without reworking the original model. The solver that we used to solve our small problem is CPLEX. As we are working with a multi-purpose scheme, we used the LP-metric tactic to turn the objective functions into a single one. While the proposed model has practical usage, the complexity of larger-scale systems requires the adoption of heuristics to solve the computational complexities. In large cases, it would be better to adopt other techniques like Genetic Algorithm or Particle Swarm Optimization due to the complexity of the problem at hand. To gain better and more reliable answers that are more realistic, the scheme should be solved on a large scale. To increase the size of the problem, we should allocate greater numbers to the sets—for example, more blood collection centers, labs, hospitals, etc. Since calculations take a long time to solve large problems with GAMS software, heuristic or meta-heuristic methods should be employed. In this paper, a small-scale numerical case is shown and solved using precise techniques in the GAMS program. The presumed value of parameters for the small size of the issue is indicated in Table 2.

Additionally, the set size of the Blood Collection Centers is 6, Labs are 2, Main Blood Centers are 2, Hospital is 1, Blood Products are 3, and Blood Groups are 4. We considered the duration of checking the SC in the network to be 12 months. For convenience, we have written the distance of cities in kilometers and the operating time in minutes.

Table 2. Parameters Values

Parameters	Value	Parameters	Value	Parameters	Value	Parameters	Value
Di_{11}	100	trl_{22}	120	tti_{41}	3.9	$envc_{52}$	2
Di_{12}	200	trl_{31}	160	tti_{42}	1.9	$envc_{61}$	8
Di_{21}	150	trl_{32}	130	tti_{51}	1.9	$envb_{11}$	5
Di_{22}	500	trl_{41}	170	tti_{52}	1.9	$envb_{21}$	2
Di_{31}	200	trl_{42}	190	tti_{61}	2.0	$envc_{62}$	9
Di_{32}	100	trl_{51}	200	tti_{62}	2.3	$envl_{11}$	1
Di_{41}	300	trl_{52}	100	ttj_{11}	1.2	$envl_{12}$	5
Di_{42}	50	trl_{61}	180	ttj_{12}	1.5	$envl_{21}$	1
Di_{51}	100	trl_{62}	100	ttj_{21}	1.0	$envl_{22}$	8
Di_{52}	100	trm_{11}	140	ttj_{22}	0.9	$exdate_{11}$	500
Di_{61}	400	trm_{12}	150	ttm_{11}	1.0	$exdate_{12}$	400
Di_{62}	200	trm_{21}	130	ttm_{21}	1.6	$exdate_{13}$	550
Dj_{11}	200	trm_{22}	200	$envc_{11}$	4	$exdate_{14}$	450
Dj_{12}	100	trh_{11}	150	$envc_{12}$	5	$Exdate_{21}$	600
Dj_{21}	400	trh_{21}	100	$envc_{21}$	5	$Exdate_{22}$	500
Dj_{22}	200	tti_{11}	1.2	$envc_{22}$	5	$Exdate_{23}$	525
Dm_{11}	200	tti_{12}	1.0	$envc_{31}$	6	$Exdate_{24}$	375
Dm_{21}	100	tti_{21}	1.1	$envc_{32}$	3	$Exdate_{31}$	550
trl_{11}	140	tti_{22}	8.7	$envc_{41}$	7	$Exdate_{32}$	430
trl_{12}	150	tti_{31}	2.9	$envc_{42}$	9	$Exdate_{33}$	490
trl_{21}	160	tti_{32}	3.4	$envc_{51}$	2	$Exdate_{34}$	600

6. Result and Discussion

6.1. Result

The outcomes of solving the scheme with GAMS software are illustrated in Tables 3 and 4:

Table 3. Model Outcomes

Variable (V1)	Value (V2)	V1	V2	V1	V2	V1	V2	V1	V2
Z_1	911144.4	X_{1229}	190.08	Y_{2213}	190.08	Z_{121111}	87	Z_{22112}	39
Z_2	39.4	X_{12210}	190.08	Y_{2214}	242.37	Z_{121112}	128.08	Z_{22113}	18
Z_3	17600.31	X_{12211}	190.08	Y_{2215}	190.08	Z_{12121}	25	Z_{22114}	48
X_{1111}	52	X_{12212}	190.08	Y_{2216}	190.08	Z_{12122}	18	Z_{22115}	27
X_{1113}	1409.92	X_{1237}	190.08	Y_{2217}	219.96	Z_{12123}	37	Z_{22116}	28
X_{1123}	2309.92	X_{1238}	190.08	Y_{2218}	212.49	Z_{12124}	38	Z_{22117}	59
X_{1131}	52	X_{1239}	190.08	Y_{2219}	205.023	Z_{12125}	29	Z_{22118}	59
X_{1143}	2309.92	X_{12310}	190.08	Y_{22110}	197.55	Z_{12126}	28	Z_{22119}	38
X_{1211}	1948	X_{12311}	190.08	Y_{22111}	190.08	Z_{12127}	54	Z_{221110}	134
X_{1212}	190.08	X_{12312}	190.08	Y_{22112}	190.08	Z_{12128}	40	Z_{221111}	72
X_{1213}	190.08	X_{1247}	190.08	Y_{2227}	190.08	Z_{12129}	57	Z_{221112}	18
X_{1214}	242.379	X_{1248}	190.08	Y_{2228}	190.08	Z_{121210}	126	Z_{22121}	20
X_{1215}	190.08	X_{1249}	190.08	Y_{2229}	190.08	Z_{121211}	25	Z_{22122}	42
X_{1216}	190.08	X_{12410}	190.08	Y_{22210}	190.08	Z_{121212}	153	Z_{22123}	19
X_{1221}	5300	X_{12411}	190.08	Y_{22211}	190.08	Z_{12131}	27	Z_{22124}	15
X_{1223}	190.08	X_{12412}	190.08	Y_{22212}	190.08	Z_{12132}	19	Z_{22125}	19
X_{1224}	190.08	X_{2121}	98	Y_{2237}	190.08	Z_{12133}	16	Z_{22126}	18
X_{1225}	190.08	X_{2133}	1500	Y_{2237}	190.08	Z_{12134}	18	Z_{22127}	50
X_{1226}	227.437	X_{2221}	3018	Y_{2238}	190.08	Z_{12135}	37	Z_{22128}	38
X_{1231}	1948	X_{2222}	2300	Y_{2239}	190.08	Z_{12136}	38	Z_{22129}	59
X_{1232}	190.08	X_{2231}	190.08	Y_{22310}	190.08	Z_{12137}	29	Z_{221210}	54
X_{1233}	249.851	X_{2241}	6252	Y_{22311}	190.08	Z_{12138}	38	Z_{221211}	48
X_{1234}	190.08	X_{3133}	2300	Y_{22312}	190.08	Z_{12139}	127	Z_{221212}	18
X_{1235}	234.908	X_{3142}	2800	Y_{2247}	190.08	Z_{121310}	134	Z_{22131}	10
X_{1236}	190.08	X_{4133}	1800	Y_{2248}	190.08	Z_{121311}	87	Z_{22132}	39
X_{1241}	5300	X_{4142}	5900	Y_{2249}	190.08	Z_{121312}	128	Z_{22133}	18
X_{1242}	257.322	X_{5133}	4700	Y_{22410}	190.08	Z_{12141}	25	Z_{22134}	48
X_{1243}	190.08	X_{6133}	2800	Y_{22411}	190.08	Z_{12142}	18	Z_{22135}	27
X_{1244}	190.08	X_{6141}	98	Y_{22412}	190.08	Z_{12143}	37	Z_{22136}	28
X_{1245}	190.08	Y_{1211}	52	Z_{12111}	27	Z_{12144}	38	Z_{22137}	59
X_{1246}	190.08	Y_{1221}	98	Z_{12112}	126.08	Z_{12145}	29	Z_{22138}	59
X_{1217}	219.965	Y_{1231}	52	Z_{12113}	158.08	Z_{12146}	38	Z_{22139}	38
X_{1218}	212.49	Y_{1241}	98	Z_{12114}	119.08	Z_{12147}	54	Z_{221310}	40
X_{1219}	205.02	Y_{2111}	4966	Z_{12115}	131.08	Z_{12148}	40	Z_{221311}	72
X_{12110}	197.55	Y_{2121}	7600	Z_{12116}	38	Z_{12149}	121	Z_{221312}	18
X_{12111}	190.08	Y_{2131}	8200	Z_{12117}	29	Z_{121410}	15	WP_1	332.8
X_{12112}	190.08	Y_{2141}	7600	Z_{12118}	38	Z_{121411}	25	WP_{12}	0.086
X_{1227}	190.08	Y_{2142}	67.2.08	Z_{12119}	127.08	Z_{121412}	153		
X_{1228}	190.08	Y_{2212}	190.08	Z_{121110}	40	Z_{22111}	10		

Table 4. Objective Functions Outcomes

Z_1^{min}	Z_2^{min}	Z_3^{min}	Z_4
911144.485	39.4	17600.313	-1.091

Because of working with a multi-purpose scheme, the LP-metric tactic is deployed to achieve a single objective value (Z_4). We first solve each objective function independently of the other objective functions. In other words, we treat each function as a single-objective issue. In this way, we get the modes Z_1^{min}, $Z_2^{min,}$ and $Z_3^{min,}$ as written in Table 4. The best-case scenario occurs when we minimize the relative deviations from the ideal value of the objective functions.

The outcomes show that blood pack transfusions are always performed between all Blood Collection Centers, Labs, Main Blood Centers, and Hospitals. All three target functions, which represent SC expenses, transport time, and environmental impacts, have the same value and weight, respectively. The best case for each of the target functions is 911144.485, 39.4, and 17600.313, respectively.

6.2. Sensitivity Analysis

Reducing and increasing some parameters can affect the outcomes. In this problem, we chose the waste percentage of the key blood centers, the waste percentage of the hospital, and the blood demand of the hospital to analyze the sensitivity of the objective functions to their different values. So, the problem is resolved in eleven different situations for each parameter. Then, the effects of shifting the parameters on the objective functions are shown in the figures.

The results of the sensitivity analysis are graphically represented to show the effect of variation in parameters. Figures 2, 3, 4, and 5 depict the sensitivity of SC costs, transportation time, environmental impacts, and the LP-metric function, respectively, to the waste percentage of the main blood center. As it can be seen in Figures 2 and 4, the lower the waste percentage, the lower the costs and environmental impacts. On the other hand, a ten percent change in waste ratio would cause a significant increase in the two measures. Interestingly, as observed in Figure 3, the transportation time does not significantly change even when there are changes in the percentages of waste.

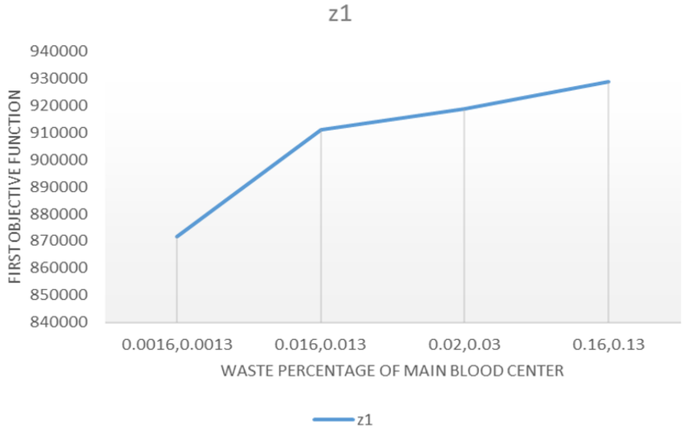

Figure 2. Waste percentage of the main blood center and cost of supply chain

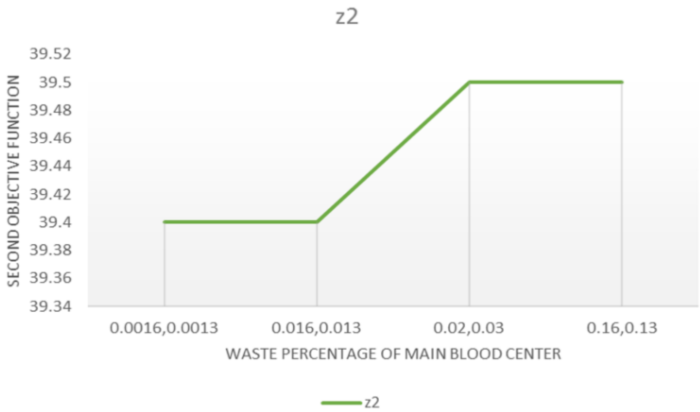

Figure 3. Waste percentage of the main blood center and transportation time

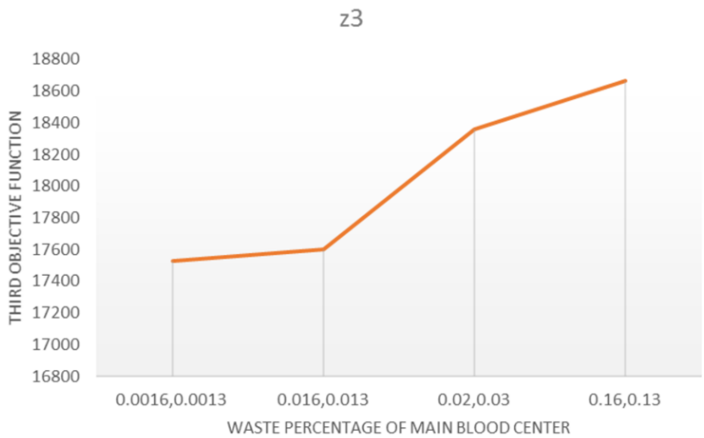

Figure 4. Waste percentage of the main blood center and environmental impacts of the network

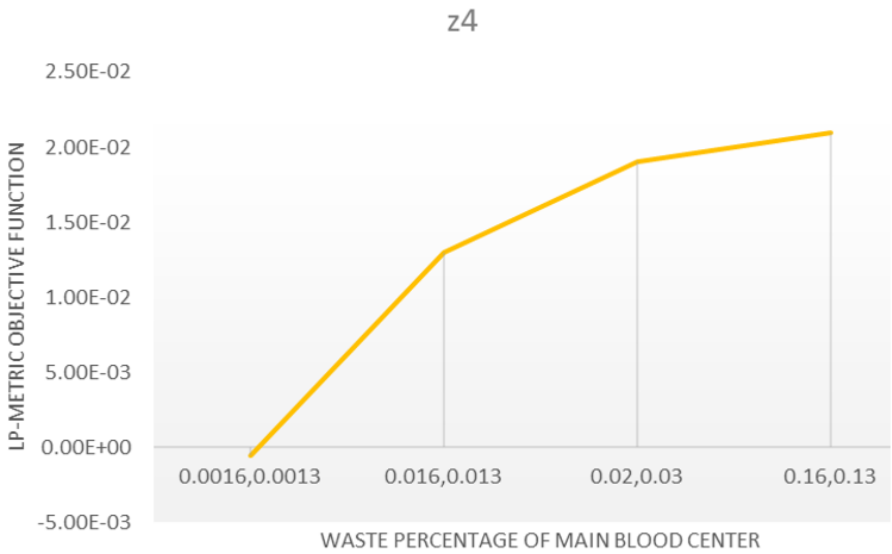

Figure 2. Waste percentage of the main blood center and LP-metric objective function

Figures 6, 7, 8, and 9 show the sensitivity of the first, second, and third objective functions and the LP-metric objective function to the waste percentage of the hospital, respectively. By reducing the waste percentage of the hospital, the number of environmental impacts remains constant, and the amount of SC expenses, transportation time, and LP-metric objective function are reduced. According to the figures, it is clear that as the percentage of waste increases, the environmental impacts decrease, the expense of the SC and time of transportation, and the LP-metric objective function have an upward slope and increase.

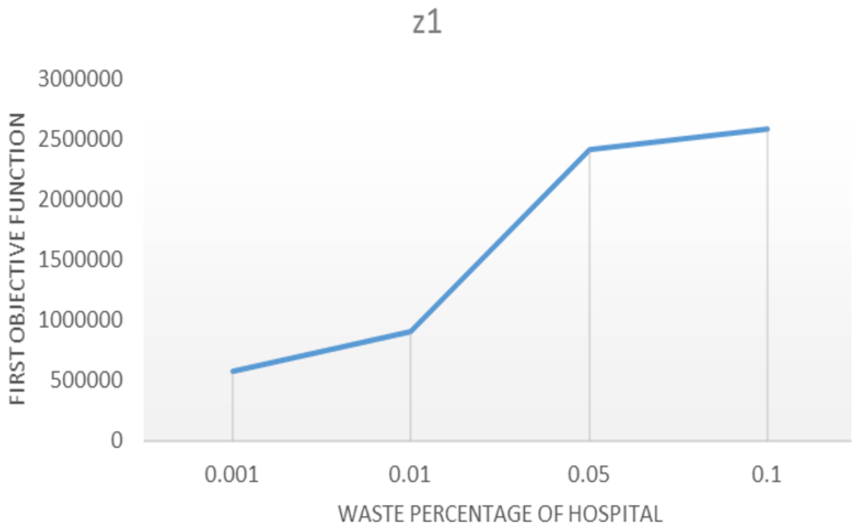

Figure 3. Waste percentage of hospital and cost of SC

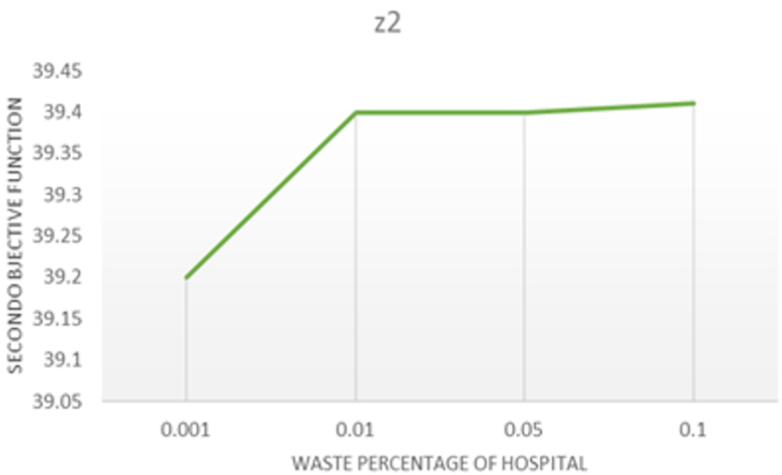

Figure 4. Waste percentage of hospital and transportation time

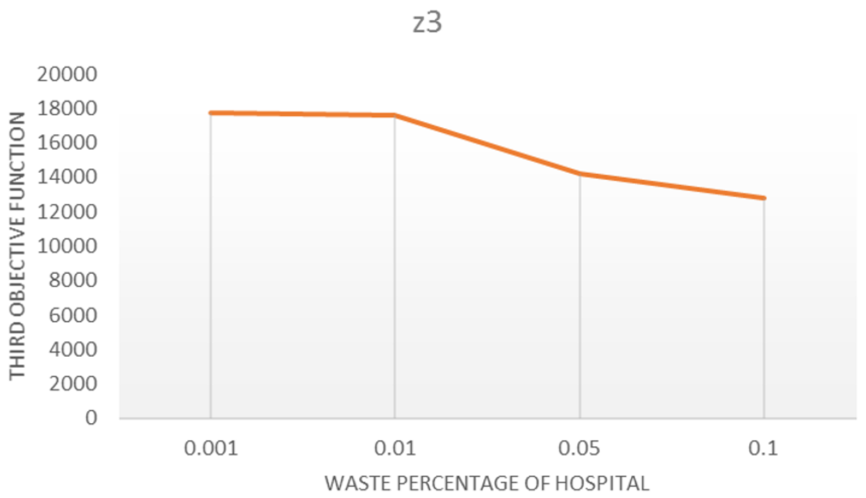

Figure 5. Waste percentage of hospital and environmental impacts of the network

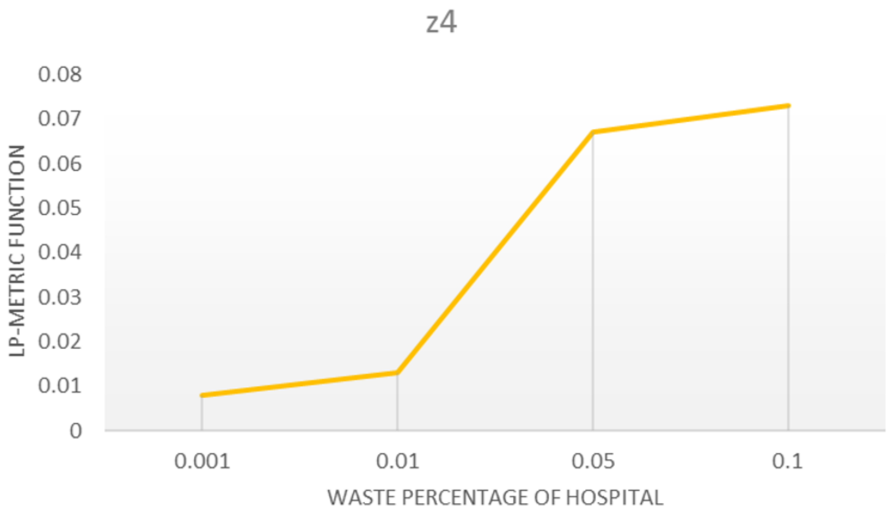

Figure 6 Waste percentage of hospital and LP-metric objective function

In this part, we measure the sensitivity of each of the target functions with changes in the blood demand of the hospital. Figures 10, 11, 12, and 13 show the sensitivity of SC expenses, transportation time, environmental impacts, and the LP-metric objective function to the blood demand of the hospital. The figures show that as demand decreases, SC expenses increase contrary to our expectations, environmental impacts decrease, and transportation time and LP-metric object function remain constant. As demand rises, the total amount of expenses decreases, and the transportation time and the LP-metric objective function increase. Environmental impacts are also increasing with an upward slope.

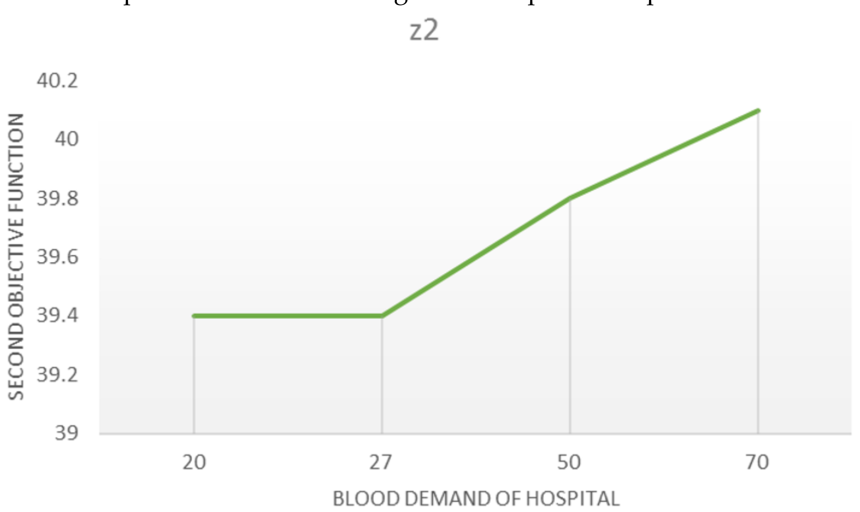

Figure 7. Blood demand of hospital and transportation time

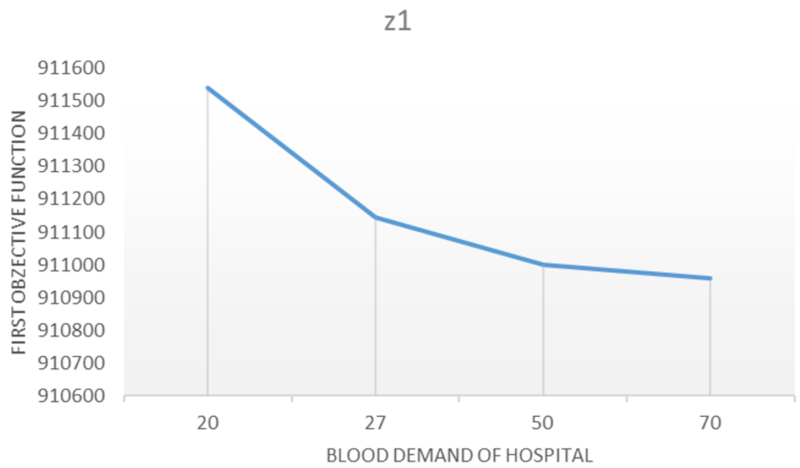

Figure 8. Blood demand of hospital and cost of supply chain

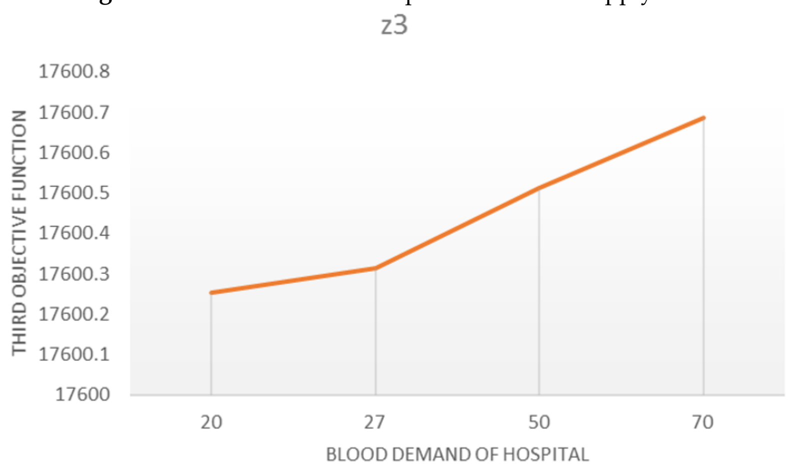

Figure 9. Blood demand of hospital and environmental impacts of the network

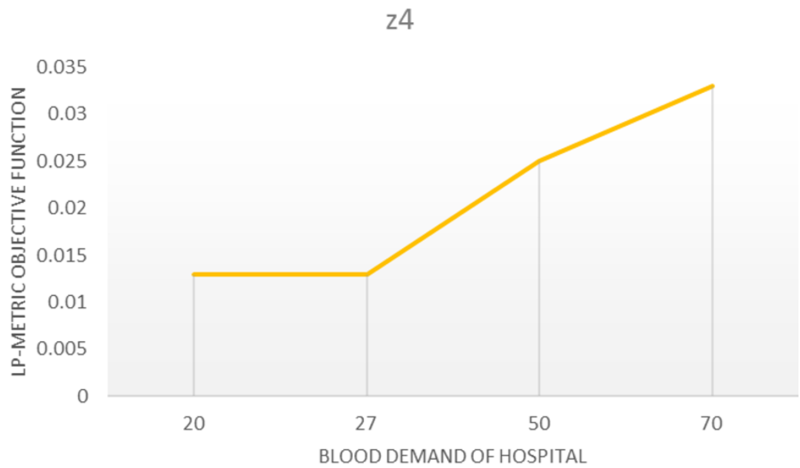

Figure 10. Blood demand of hospital and LP-metric objective function

7. Discussion

There are some real-world applications and management gains to be had from this investigation. Green SC network design has been the focus of a lot of recent studies, including those by Heidari-Fathian and Pasandideh [15] and Eskandari-Khanghahi *et al*. [16]. However, most of them have applied green constraints on the GHG emissions of the network. There are lots of other parts of an SC that may cause undesirable impacts on the environment, such as waste in subsystems. In this investigation, this issue has been tackled by integrating the waste produced in each center and the GHG emissions caused by transportation between centers.

Furthermore, many explorations, such as those done by Fahimnia *et al*. [19], Khalilpourazari and Khamseh [17], and Salehi *et al*. [13], the expiration date of blood products is not considered in the constraints, while in this investigation, we have included three blood products as well as the perishability time of these products in the scheme to make the outcomes more reliable and close to reality. Moreover, unlike many other studies, such as research by Fahimnia *et al*. [22] and Asadpour *et al*. [23], in this investigation, we have considered the blood demand in hospitals to be stochastic and have solved the scheme with uncertain demand. Considering that the objectives of this investigation are network expenses, transportation time between centers, environmental impacts, and the constraints related to blood product expiration, the outcomes and sensitivity analysis can help managers make informed decisions and allocate resources properly to lower expenses and transport time; while keeping an eye on the consequences the network will have on the environment.

In terms of scalability, although the suggested precise solution algorithm (CPLEX) ensures global optimality in small-to-middle scale cases, it is restricted in computation with large-scale real-life networks since the issue is NP-hard. The solution time increases exponentially as the number of nodes (hospitals and centers) increases. In these large-scale cases the heuristic and metaheuristic methods (such as, Genetic Algorithms, NSGA-II or Particle Swarm Optimization) are suggested as the alternative ones. Although these approximate techniques minimize the assure of optimum, they provide highly reduced computational times (polynomial complexity), which in turn makes it more workable in dynamic and large-scale national blood supply network.

One should take note of some of the modeling assumptions. To start with, we took the demand to follow a normal distribution. Although rare blood groups tend to follow a Poisson distribution, the Central Limit Problem indicates that the aggregated demand at the hospital level (combining many patients) takes a normal form, which is adequate to plan tactically. Second, on the shelf-life constraint (Eq. 9), the model adds transportation and operation times in a linear manner. In a complicated mesh network, this is a conservatization of the longest path. Although this eases the real flow splitting, it guarantees that any solution arrived at is also resistant to the risk of expiration, giving a safe upper limit to the decision-makers.

8. Conclusion and Future Investigations

In this investigation, a 4-echelon, three-objective LP scheme for green blood SCND with stochastic demand was recommended. The four echelons include blood collection centers, labs, main blood centers, and hospitals. The three objectives of the scheme are network expenses, including establishment, operations, transportation and inventory expenses, transportation time, and detrimental environmental impacts of the network, including GHG emissions while transportation and wastes in each center, which the scheme tries to lower. The important factors taken into consideration in this model are three blood products, including red blood cells, platelets, and plasma, blood product expiration date, and stochastic demand. A sensitivity analysis is done on blood demand and waste percentage to check their effects on the objective functions to create an appropriate green blood SCND.

For future studies, extending the size of the scheme and solving it with heuristic and meta-heuristic methods is recommended. It is also possible to consider shortage minimization and test reliability maximization in the objectives and use varied solution methods such as ε-constraint, goal programming, utility function, etc.

Availability of data and materials

Data can be shared upon request.

Competing interests

The scholars assert no competing interests.

CRediT Author Contribution Statement

Xu Guo: Writing-Original draft preparation, Conceptualization, Supervision, Project administration.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Ethical Approval

The paper has attained ethical approval from the institutional review board, ensuring the protection of participants' rights and conformity with ethical regulationss.

References

[1] Mohammad Alipour-Vaezi, Amir Aghsami and Fariborz Jolai, "Prioritizing and Queueing the Emergency Departments' Patients Using a Novel Data-Driven Decision-Making Methodology, A Real Case Study", *Expert Systems with Applications*, Print ISSN: 0957-4174, Online ISSN: 1873-6793, 1 June 2022, Vol. 195, p. 116568, Published by Elsevier, DOI: 10.1016/j.eswa.2022.116568, Available: https://www.sciencedirect.com/science/article/pii/S0957417422000665.

[2] Mahdieh Masoumi, Amir Aghsami, Mohammad Alipour-Vaezi, Fariborz Jolai and Behdad Esmailifar, "An M/M/C/K Queueing System in an Inventory Routing Problem Considering Congestion and Response Time for Post-Disaster Humanitarian Relief: A Case Study", *Journal of Humanitarian Logistics and Supply Chain Management*, Print ISSN: 2042-6747, Online ISSN: 2042-6755, 22 March 2022, Vol. 12, No. 2, pp. 182–219, Published by Emerald, DOI: 10.1108/JHLSCM-12-2020-0119, Available: https://www.emerald.com/jhlscm/article/12/2/182/222016.

[3] Vijay Lahri, "Assessment of Critical Drivers Towards Sustainable Green Supply Chain Performance Management", *International Journal of Business Performance and Supply Chain Modelling*, Online ISSN: 1758-941X, 2 October 2020, Vol. 11, No. 3, pp. 228–251, Published by Inderscience, DOI: 10.1504/IJBPSCM.2020.110217, Available: https://www.inderscienceonline.com/doi/abs/10.1504/IJBPSCM.2020.110217.

[4] Hossein Shakibaei, Mohammad Reza Farhadi-Ramin, Mohammad Alipour-Vaezi, Amir Aghsami and Masoud Rabbani, "Designing a Post-Disaster Humanitarian Supply Chain Using Machine Learning and Multi-Criteria Decision-Making Techniques", *Kybernetes*, Print ISSN: 0368-492X, Online ISSN 1758-7883, 1 March 2023, Vol. 53, No. 5, Published by Emerald, DOI: 10.1108/K-10-2022-1404, Available: https://www.emerald.com/k/article-abstract/53/5/1682/1212723.

[5] Prashant Chintapalli, "Simultaneous Pricing and Inventory Management of Deteriorating Perishable Products", *Annals of Operations Research*, Prin ISSN: 0254-5330, Online ISSN: 1572-9338, June 2015, Vol. 229, pp. 287–301, Published by Springer, DOI: 10.1007/s10479-014-1753-9, Available: https://link.springer.com/article/10.1007/s10479-014-1753-9.

[6] Zahra Mohammadnazari, Mobina Mousapour Mamoudan, Mohammad Alipour-Vaezi, Amir Aghsami, Fariborz Jolai *et al.*, "Prioritizing Post-Disaster Reconstruction Projects Using an Integrated Multi-Criteria Decision-Making Approach: A Case Study", *Buildings*, Online ISSN: 2075-5309, 27 January 2022, Vol. 12, No. 2, p. 136, Published by MDPI, DOI: 10.3390/buildings12020136, Available: https://www.mdpi.com/2075-5309/12/2/136.

[7] Mohammad Alipour-Vaezi, Amir Aghsami and Masoud Rabbani, "Introducing a Novel Revenue-Sharing Contract in Media Supply Chain Management Using Data Mining and Multi-Criteria Decision-Making Methods", *Soft Computing*, Print ISSN: 1432-7643, Online ISSN: 1433-7479, March 2022, Vol. 26, No. 6, pp. 2883–2900, Published by Springer, DOI: 10.1007/s00500-021-06609-0, Available: https://link.springer.com/article/10.1007/s00500-021-06609-0.

[8] Seyed Mojib Zahraee, Jafri Mohd Rohani, Alireza Firouzi and Ataollah Shahpanah, "Efficiency Improvement of Blood Supply Chain System Using Taguchi Method and Dynamic Simulation", *Procedia Manufacturing*, ISSN: 2351-9789, 2015, Vol. 2, pp. 1–5, Published by Elsevier, DOI: 10.1016/j.promfg.2015.07.001, Available: https://www.sciencedirect.com/science/article/pii/S2351978915000025.

[9] Mohammad Reza Ghatreh Samani, S. Ali Torabi and Seyyed-Mahdi Hosseini-Motlagh, "Integrated Blood Supply Chain Planning for Disaster Relief", *International Journal of Disaster Risk Reduction*, Online ISSN: 2212-4209, Vol. 27, pp. 168–188, March 2018, Published by Elsevier, DOI: 10.1016/j.ijdrr.2017.10.005, Available: https://www.sciencedirect.com/science/article/pii/S2212420917302960.

[10] Pourdel Bahador, Seyed Abolfazl Hosseini, Erfan Rajabi and Amirali Alizadeh A, "Alarm Fatigue in the Operating Room: A Synthesis of the Dual Threat from Device Overload and Ambient Noise", *Perioperative Care and Operating Room Management*, Online ISSN: 2405-6030, March 2026, Vol. 42, p. 100624, Published by Elsevier, DOI: 10.1016/j.pcorm.2026.100624, Available: https://www.sciencedirect.com/science/article/abs/pii/S2405603026000166.

[11] Andres F. Osorio, Sally C. Brailsford and Honora K. Smith, "A Structured Review of Quantitative Models in the Blood Supply Chain: A Taxonomic Framework for Decision-Making", *International Journal of Production Research*, Print ISSN: 0020-7543, Online ISSN: 1366-588X, 9 February 2015, Vol. 53, No. 24, pp. 7191–7212, Published by Taylor

& Francis, DOI: 10.1080/00207543.2015.1005766, Available: https://www.tandfonline.com/doi/abs/10.1080/00207543.2015.1005766.

[12] Ilhan Or and William P. Pierskalla, "A Transportation Location-Allocation Model for Regional Blood Banking", *AIIE Transactions*, Print ISSN: 0569-5554, Online ISSN: 2374-7536, 6 July 2007, Vol. 11, No. 2, pp. 86–95, Published by Taylor & Francis, DOI: 10.1080/05695557908974447, Available: https://www.tandfonline.com/doi/abs/10.1080/05695557908974447.

[13] Faraz Salehi, Masoud Mahootchi and Seyed Mohammad Moattar Husseini, "Developing a Robust Stochastic Model for Designing a Blood Supply Chain Network in a Crisis: A Possible Earthquake in Tehran", *Annals of Operations Research*, Print ISSN: 0254-5330, Online ISSN: 1572-9338, December 2019, Vol. 283, pp. 679–703, Published by Springer, DOI: 10.1007/s10479-017-2533-0, Available: https://link.springer.com/article/10.1007/s10479-017-2533-0.

[14] Mary Dillon, Fabricio Oliveira and Babak Abbasi, "A Two-Stage Stochastic Programming Model for Inventory Management in the Blood Supply Chain", *International Journal of Production Economics*, Print ISSN: 0925-5273, Online ISSN: 1873-7579, May 2017, Vol. 187, pp. 27–41, Published by Elsevier, DOI: 10.1016/j.ijpe.2017.02.006, Available: https://www.sciencedirect.com/science/article/pii/S0925527317300361.

[15] Hassan Heidari-Fathian and Seyed Hamid Reza Pasandideh, "Green-Blood SUPPLY Chain Network Design: Robust Optimization, Bounded Objective Function & Lagrangian Relaxation", *Computers & Industrial Engineering*, Print ISSN: 0360-8352, Online ISSN: 1879-0550, August 2018, Vol. 122, pp. 95–105, Published by Elsevier, DOI: 10.1016/j.cie.2018.05.051, Available: https://www.sciencedirect.com/science/article/pii/S0360835218302602.

[16] M. Marzieh Eskandari-Khanghahi, Reza Tavakkoli-Moghaddam, Ata Allah Taleizadeh and Saman Hassanzadeh Amin, "Designing and Optimizing a Sustainable Supply Chain Network for a Blood Platelet Bank under Uncertainty", *Engineering Applications of Artificial Intelligence*, Print ISSN: 0952-1976, Online ISSN: 1873-6769, May 2018, Vol. 71, pp. 236–250, Published by Elsevier, DOI: 10.1016/j.engappai.2018.03.004, Available: https://www.sciencedirect.com/science/article/pii/S0952197618300538.

[17] Soheyl Khalilpourazari and Alireza Arshadi Khamseh, "Bi-Objective Emergency Blood Supply Chain Network Design in Earthquake Considering Earthquake Magnitude: A Comprehensive Study with Real World Application", *Annals of Operations Research*, Print ISSN: 0257-5330, Online ISSN: 1572-9338, December 2019, Vol. 283, pp. 355–393, Published by Springer Verlag, DOI: 10.1007/s10479-017-2588-y, Available: https://link.springer.com/article/10.1007/s10479-017-2588-y.

[18] Fatemeh Ameri, Azam Sabahi, Negar Ranjbar, Seyed Reza Hoseini, Reyhaneh Khosrojerdi *et al.*, "Internet of Things (IoT) Applications in Hospitals: A Systematic Review", *Health Technology Assessment in Action*, Online ISSN: 2645-5817, 31 July 2022, Vol. 5, No. 4, Published by KNE Publishing, DOI: 10.18502/htaa.v5i4.10170, Available: https://publish.kne-publishing.com/index.php/HTAA/article/view/10170.

[19] Shuanglin Li, Na Zhang and Jin Qin, "An Inter-Regional Lateral Transshipment Model to Massive Relief Supplies with Deprivation Costs", *Mathematics*, Online ISSN: 2227-7390, 17 July 2025, Vol. 13, No. 14, p. 2298, Published by MDPI, DOI: 10.3390/MATH13142298, Available: https://www.mdpi.com/2227-7390/13/14/2298.

[20] Khira Belgada and Laila El Abbadi, "Blockchain and Industrial Traceability: Insights from a Systematic Literature Review Within Industry 4.0 Contexts", *Engineering Proceedings*, Online ISSN: 2673-4591, 3 December 2025, Vol. 112, No. 1, p. 74, Published by MDPI, DOI: 10.3390/engproc2025112074, Available: https://www.mdpi.com/2673-4591/112/1/74.

[21] Ahmed Esmail Mohamed and Kim Tuan Anh Huynh, "Mitigating the Bullwhip Effect and Enhancing Supply Chain Performance Through Demand Information Sharing: An ARENA Simulation Study", *Journal of Economics and Sustainable Development*, Print ISSN: 2222-1700, Online ISSN: 2222-2855, 31 August 2023, Vol. 14, No. 14, pp. 78-165, Published by International Institute for Science, Technology and Education (IISTE), DOI: 10.7176/JESD/14-14-07, Available: https://iiste.org/Journals/index.php/JEDS/article/view/61397.

[22] Behnam Fahimnia, Armin Jabbarzadeh, Ali Ghavamifar and Michael Bell, "Supply Chain Design for Efficient and Effective Blood Supply in Disasters", *International Journal of Production Economics*, Print ISSN: 0925-5273, Online ISSN: 1873-7579, January 2017, Vol. 183, pp. 700–709, Published by Elsevier, DOI: 10.1016/j.ijpe.2015.11.007, Available: https://www.sciencedirect.com/science/article/pii/S0925527315004508.

[23] M. Asadpour, Omid Boyer and R. Tavakkoli Moghaddam, "A blood Supply Chain Network with Backup Facilities Considering Blood Groups and Expiration Date: A Real-World Application", *International Journal of Engineering*, Print ISSN: 1025-2495, Online ISSN: 1735-9245, February 2021, Vol. 34, No. 2, pp. 470–479, Published by Isfahan University of Technology (IUT Press), DOI: 10.5829/ije.2021.34.02b.19, Available: https://www.ije.ir/article_122808.html.