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Original Article

Implement a Two-Tier Donation Approach to Optimize the Humanitarian Pharmaceutical Inventory by Employing a Collaborative Decision-Making

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***Abstract** - This study explores the coordination of a three-echelon Humanitarian Pharmaceutical Supply Chain (HPSC) involving a Pharmaceutical Company (PC), a Local Humanitarian Logistic Provider (LHLP), and a Regional Humanitarian Logistic Provider (RHLP) with a focus on economic objectives and the challenges posed by uncertain demand. In this regard, a two-tier donation scheme is introduced to optimize the humanitarian inventory and to preserve the environmental and economic aspects of the HPSC. At the beginning of the distribution period, the PC establishes the donation quantity. Afterwards, the LHLP determines the quantity of medications to be ordered. Subsequently, at the specified time within the cycle, the RHLP decides regarding the quantity to be taken back. Then, the PC will retrieve the donation quantity from the returned quantity. To effectively coordinate the HPSC, a bi-level optimization scheme is developed. The numerical results demonstrate that implementing the proposed bi-level optimization collaborative scheme not only enhances total channel profit but also encourages all members to make decisions in line with integrated sustainable HPSC goals.*

***Keywords** - Humanitarian supply chain, Reverse Logistics, Cooperative decision-making, Expired drugs, Donation.*

1. Introduction

Medicine's donation is considered as generous acts from pharmaceutical companies and humanitarian organizations. It is carried out as an act of compassion or as part of a company's social responsibility, with the goal of providing drugs to countries in vulnerable situations [1]. Ensuring equitable access to medication is the primary objective of humanitarian supply chain organizations [2]. It coordinates life-saving operations in response to pandemics, natural disasters and the regular supply of medicines to underdeveloped countries [3]. Managing inventory in humanitarian pharmaceutical operations is considerably more complex than managing inventory for commercial products [4]. The main challenges are coming from:

- High forecast fluctuation [5]
- Irrelevant inventory management process [4]
- Low collaboration between stakeholders [6]

Global humanitarian agencies are establishing contracts with pharmaceutical and logistic vendors to manufacture and distribute medicines to the recipient countries [7]. The main weakness of this configuration is that the entire supply chain operations are built based on the wrong demand signal[8, 9]. Figure 1 shows the forecast error consequences. Since the forecast is highly inaccurate, some Global health alliances prefer to overestimate the forecast [10] to ensure the medication program well covers the patients. Thus, it is important to focus on forecasting enhancement and minimize inventory risks. Furthermore, the generated high stock is not stored in accordance with the established standards [11]. Consequently, the donated quantity is retained until it reaches the "end of life" date. During an audit conducted by a Swiss expert, it was estimated that half of the drugs donated to Albania were deemed "inappropriate or useless" and would need to be destroyed [12]. Also, a study published in the New England Journal of Medicine in 1996 found that about 50% of the drugs donated to Bosnia were of little or no use [13]. In order to develop comprehensive guidelines, the World Health Organization (WHO) conducted a systematic review of drug donations from 1997 to 2007. The review revealed that only 55% of the donations were appropriate based on the specific characteristics of the events and the actual needs of the recipients. Additionally, it was found that recipient countries received only 13% of the drugs they had requested. This highlights the need for improved practices and better alignment between donations and the actual requirements of the recipients [14]. Inventory management in humanitarian healthcare requires utmost attention due to the significant risk of counterfeit drugs. Proper disposal of expired medicines is crucial to prevent any adverse impact on human health and the environment. These practices align with the guidelines set forth by the World Health Organization (WHO) [14]. To ensure the safe disposal of expired medicines, the upstream actors in the pharmaceutical supply chain bear the responsibility of securely destroying the expired pharmaceutical stock. They are accountable for complying with government regulations to prevent incurring substantial penalties for retaining expired drugs. The integration of reverse logistics into humanitarian pharmaceutical supply chains presents a valuable opportunity to address the challenges associated with over-forecasting in inventory management and reduce write-off costs. This not only saves lives but also improves profitability and holds potential benefits for the environment. While reverse logistics has been extensively examined in the context of commercial pharmaceutical business units, primarily driven by growth objectives, its application in humanitarian supply chains has received less attention.

An optimal concept for humanitarian reverse logistics involves recovering excess pharmaceutical products before they reach their minimum accepted shelf life in alternative countries. However, to foster motivation and engagement among all stakeholders in the Humanitarian Pharmaceutical Supply Chain (HPSC) and generate enthusiasm for the reverse logistics process, a cooperative model structure is necessary. This structure enables the sharing of risks and benefits among actors based on contractual agreements, creating synergy. Implementing appropriate cooperative conditions ensures the benefits of HPSC actors and aligns with the overall objective of global health organizations, which is to serve the maximum number of vulnerable patients. By fostering cooperation and synergy, the humanitarian reverse logistics process can be enhanced to its fullest potential, leading to improved outcomes for all involved parties.

Engaging in the review of global annual reports yields significant advantages, as it offers valuable insights into past achievements and outlines the future strategies to be implemented. These reports serve as a valuable resource, providing comprehensive information on the global directions and priorities of the Humanitarian Supply Chain (HSC). By examining these reports, understanding the HSC landscape allows staying informed about its evolving strategies and focus areas. A study was conducted [5] to analyze the reports of the 14 leading humanitarian agencies, including organizations like UNICEF, WHO, and UNDP. The findings of the research indicated that a significant number of these global organizations did not explicitly address the topic of Reverse Logistics (RL) in their reports. Moreover, only a small proportion of the documents discussed RL as a viable tool for sustainable supply chain management. These findings suggest that the concept of RL receives low attention within the humanitarian context. To delve deeper into this issue, Peretti, Tatham, Wu, and Sgarbossa [5] conducted a comprehensive review of post-mission reports from the IFRC (International Federation of Red Cross and Red Crescent Societies) field database, covering a three-year period from 2010 to 2012. A total of 117 reports documenting individual operations carried out globally by the International Federation of Red Cross and Red Crescent Societies (IFRC) were examined. The study revealed that only 24% of the operational reports covered topics pertaining to reverse logistics. This finding was anticipated, considering that reverse logistics is primarily perceived as an operational concept. Notably, the predominant discussions within these reports centered around donation activities and reconditioning efforts. This paper focuses on the humanitarian inventory optimization activities within a Humanitarian Pharmaceutical Supply Chain (HPSC) and presents an innovative approach to collecting excess medications before they expire. In this study, the donation process operates at two levels. The global alliance provides funding for the first level, distributing the initial quantity Q to the primary country. The second level is funded by the PC, which redistributes the donation quantity G from the leftover q to the secondary country.

Additionally, the study assumes that the regional humanitarian logistic provider (RHLP) visits the Local Humanitarian Logistic Provider (LHLP) inventory at specific times throughout the cycle. Surplus medications are retrieved based on realized demand. Subsequently, the PC decides how much of the collected surplus will be allocated for the announced donation. By implementing this scheme, the paper aims to prevent humanitarian pharmaceutical waste and its associated negative consequences while enhancing sustainable practices throughout the chain. Considering the interconnectedness of humanitarian supply chain members, the decisions made by one member significantly impact the profitability of others within the HPSC. Thus, a centralized decision-making approach, with a central decision maker representing the channel members, can enhance overall supply chain profitability. However, implementing a centralized approach may conflict with the individual profits of certain channel members. Coordination among supply chain members is crucial for the success of humanitarian activities. Various coordination mechanisms have been developed in the pharmaceutical commercial area in the literature to encourage integrated decision-making and participation among members. However, the existing literature on the coordination approach in the humanitarian space is still relatively limited or underdeveloped. In the pharmaceutical industry, while there has been a significant amount of research on various management aspects, there has been limited focus on developing analytical and mathematical inventory models specifically tailored to sustainable solutions within Humanitarian Pharmaceutical Supply Chains (HPSCs). This study builds upon the works of Modak, Tat et al., and Zeng by introducing a ship-back concept in HPSCs to recover excess medications before they expire.

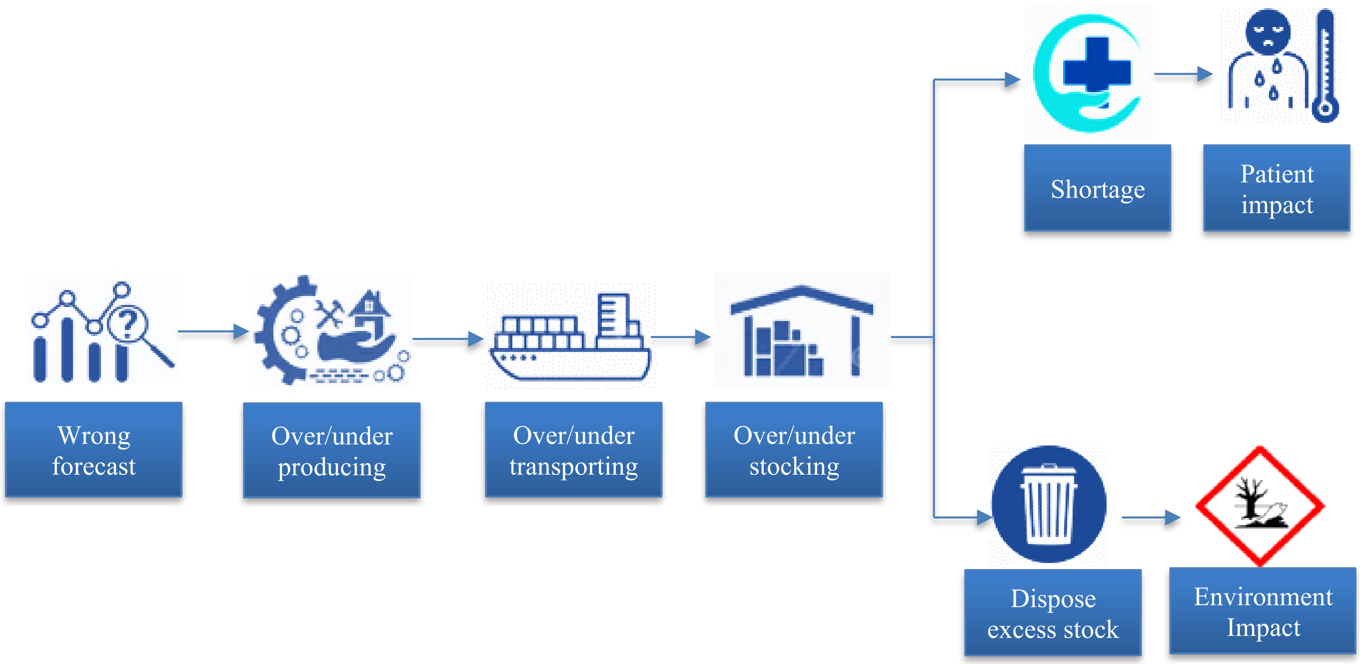

Fig. 1 Forecast error consequence on humanitarian supply chain

The research contributes uniquely to the field of pharmaceutical sustainability by proposing a new "two-level donation" strategy that effectively addresses both economic and environmental concerns. Additionally, it suggests a collaborative bi-level optimization scheme to harmonize operations within a three-tier HPSC facing uncertain demand, filling a gap in current research. This paper is organized as follows: Section II presents the state-of-the-art overview of the reverse logistic and cooperative decision model. Section III describes the proposed HPSC model. Section IV provides the mathematical formulation of the proposed model. Section V presents the proof of concept through a numerical analysis to illustrate the results. Section VI provides the conclusion, challenges, and future work.

2. Literature Review

This section of the study focuses on four significant literature streams closely related to our research. Firstly, a summary of the current literature on the humanitarian pharmaceutical supply chain will be provided. This review aims to offer a comprehensive insight into the various challenges facing the HPSC. Secondly, a comprehensive examination of the available literature regarding inventory management within humanitarian supply chains will be conducted. The objective is to present the different methods and tactics used to handle inventory within humanitarian operations. Thirdly, the literature on reverse logistics within humanitarian and commercial entities will be explored. This review seeks to analyze the methods and tactics utilized in handling the reverse flow of goods, encompassing product returns, recycling, and disposal. Studying the reverse logistics processes in these contexts offers insights into effective management approaches for handling product recalls, reducing waste, and enhancing sustainability within supply chains. Furthermore, a brief overview of the pertinent research on supply chain coordination will be provided. This literature review explores the different coordination mechanisms employed in supply chain management and their impact on performance, efficiency, and collaboration among supply chain partners. The study is confined to English-language publications, primarily spanning from 2000 to 2024. The search criteria involve four keyword categories: (1) synonyms for Humanitarian Pharmaceutical Supply Chain (HPSC), (2) terms related to the concept of Reverse Logistics (RL), (3) collaborative decision-making, and (4) inventory management. Various multidisciplinary databases, such as Scopus, Springer, ResearchGate, and IEEE, were utilized, along with numerous websites of global humanitarian organizations, to gather relevant information.

2.1. Literature Review of HPSC Challenges

Scholars, practitioners, and governments have shown substantial interest in the management of humanitarian supply chains [15], [16]. While effective supply chain management is vital for multiple industries, disruptions in the Humanitarian Pharmaceutical Supply Chain (HPSC) can have profound consequences for patient safety and the overall healthcare ecosystem [17]. Events like the COVID-19 pandemic have further highlighted the urgency and visibility of this issue [18], [19], [20]. Consequently, a growing body of research has emerged, examining the implications of pandemics on supply chains, focusing on resilience, decision support, and production recovery plans [21], [22], [23], [24], [25]. However, limited attention has been given to the criticality of maintaining optimal levels of medical stock in HPSC. The increase in natural disasters and unforeseen events, coupled with the accompanying uncertainties and risks, has had a notable effect on the availability, accessibility, and affordability of medical supplies. This circumstance has resulted in panic buying and stockpiling, creating unexpected demand shocks, stockouts, and extensive disruptions within the Humanitarian Pharmaceutical Supply Chain (HPSC). These medical stockouts have posed significant challenges for humanitarian logistics and governments, increasing the risks associated with delivering medical relief to patients and their communities [26], [27] [28], [29], [30]. In times of wars and natural disasters, the focus shifts towards prioritizing the global availability of essential medical supplies, surpassing considerations of cost and profit. It becomes crucial for businesses, humanitarian logistics organizations, and governments to operate within a less strained inventory framework within the global Humanitarian Pharmaceutical Supply Chain (HPSC) network. The risks of stockout or high stock could be reduced through effective medicine management based on collaboration among key stakeholders [31]. Collaborative decision-making has been advocated in pharmaceutical supply chains concerning inventory review periods and coordination among third- and fourth-party logistics service providers [32].

Existing research on optimal medicine stocks primarily focuses on uncertain lead times and demands, assuming that uncertainty and risk probabilities can be estimated [33]. However, the limited knowledge surrounding natural disasters exacerbates stock management issues. The HPSC suffers from challenges related to demand forecasting and order planning, as well as a lack of data and metrics [34] for performance measurement [35]. The preference for overestimating medical stock forecasts in humanitarian logistics contradicts the objectives of commercial supply chains, which aim to reduce inventories and expenses while improving customer service [36]. The negative effects of conflicting inventory management objectives in HPSC are further amplified by the lack of collaborative planning, forecasting, and replenishment practices in the healthcare sector [36]. The absence of a cohesive and integrated logistics strategy, coupled with various constraints in logistics components such as transportation and distribution infrastructure, procurement processes, closed international borders, and inadequate human resources, has a substantial impact on the resilience of the Humanitarian Pharmaceutical Supply Chain (HPSC) [37]. Some reviews in HPSC research emphasize the effectiveness of supply chain collaboration in managing counterfeits and drug shortages and enhancing resilience [38], [32], [39]. Additionally, there is relevant knowledge about agility and resilience as key determinants of humanitarian supply chain performance and competitiveness [40], [29], [41]. While collaboration is recognized as a crucial strategy in responding to humanitarian events and improving overall supply chain performance [42], [43], the potential of collaborative risk management capabilities in supply chains to enhance the resilience of HPSC against systematic stockout disruptions during a global pandemic has yet to be fully explored.

2.2. Literature Review of Humanitarian Inventory Management

Researchers have extensively studied the Humanitarian Pharmaceutical Supply Chain (HPSC) from various perspectives. The primary emphasis in HPSC is to meet the demands of patients and ensure a high level of Patient Service Level as it directly affects their lives and health. In the context of HPSC, the costs associated with shortages are considered more crucial than other inventory costs due to the potential health outcomes they may cause [44]. Numerous researchers have investigated HPSC, particularly focusing on the downstream part of the supply chain, to optimize inventory and transportation management costs while ensuring customer service levels. For example, a study [45] conducted in 2012 proposed decision approaches for determining reorder points and managing inventory under periodic review policies within HPSC. In a study [46]conducted in 2013, researchers explored inventory management and distribution policies in healthcare supply chains. From an economic perspective, researchers have examined various aspects of HPSC, including inventory management, product replenishment, procurement, storage, and distribution policies, with the aim of reducing costs and increasing productivity and responsiveness. In prior research, a novel approach to logistic and inventory management in hospitals was presented, emphasizing service improvement and supply chain coordination [47]. Furthermore, the optimization of inventory management in healthcare supply chains has been explored by other researchers [48].

In previous studies [49], researchers conducted investigations into various aspects of inventory management and decision-making within the pharmaceutical industry. Their objectives ranged from optimizing total inventory costs and ensuring consumer service levels are met to developing optimization approaches for pharmaceutical inventory models with multi-period continuous review and multiple products [50]. Furthermore, researchers [51] analyzed the healthcare inventory control problem with the aim of optimizing stock levels and order policies and minimizing supply chain costs in the presence of supply disruptions. Another focus [52] was on exploring reverse logistics strategies to mitigate pharmaceutical waste and introducing negotiation approaches to coordinate the Patient Supply Chain [53]. To address pharmaceutical wastage and prevent government penalties, scholars [52] proposed buyback policies to collect excess medicines before they expire and sell them in the secondary market. They also explored the combination of buyback and shortage risk contracts to coordinate the Patient Supply Chain. Additionally, researchers [54] provided a comprehensive overview of research developments and decision-support challenges in inventory management within the pharmaceutical industry. The pharmaceutical industry faces substantial challenges due to the perishability and fixed lifetimes of its products. In order to mitigate the risk of shortages and maintain satisfactory customer service levels, downstream members of the industry often opt to order large volumes of products. However, this ordering policy increases the likelihood of leftover and expired medicines. Scholars have underscored the significance of implementing reverse logistics and green supply chain practices to reduce and appropriately dispose of inevitable pharmaceutical waste. By adopting these practices, environmental concerns within the pharmaceutical supply chain can be effectively addressed [55].

2.3. Literature Review of Reverse Logistics in Humanitarian Supply Chain

The concept of reverse logistics offers numerous advantages and solutions to commercial pharmaceutical business units. Considering its profitability and benefits in that context, it may be highly advantageous to adapt and apply reverse logistics principles to the humanitarian supply chain. By incorporating reverse logistics practices, the humanitarian supply chain can potentially achieve improved efficiency, cost-effectiveness, waste reduction, and enhanced sustainability. This adaptation can enable effective management of product returns, recycling, and disposal, thereby addressing the unique challenges and requirements of the humanitarian context [5].

Meanwhile, the literature on reverse logistics incorporated in the context of humanitarian supply chains looks isolated, and its applications are scarce. A literature review was conducted, encompassing a total of 174 articles, of which 74% were published within the last three years [40], [56]. The main outcome of this research confirms that reverse logistics has limited attention on the academic state of the art in the humanitarian supply chain area[5]. Furthermore, there is a lack of framework for understanding challenges and solutions [57]. For instance, a proposal was made to integrate reverse logistics into the supply operations of the HPSC [58]. The authors highlighted the potential barriers that hinder its development. In a similar vein, other researchers [59] have suggested utilizing reverse logistics to address environmental concerns and promote the development of green logistics. However, there is no discussion or recommendation on operational aspect. This is a gap that this paper aims to fill. The literature review for the RL in the commercial context is rich and well-developed by many authors[60]. They have approached this concept from different perspectives[48], and they have surrounded both strategic and operational dimensions[61], [62]. They have focused on stock management[63], order processing policies[64], storage conditions, and distribution model of drugs from the commercial point of view [52] and appropriate service levels [32], [45], [65] [50]. In a compelling article published in 2020 by authors Roya Tat, Jafar Heydari, and Masoud Rabbani, an alternative market for redistributing medicines was examined. The authors introduced a novel mathematical model of a coordination mechanism designed to facilitate reverse logistics in the commercial sector [66]. More attention has been given to environmental questions and collecting leftover and expired drugs due to negligible salvage value and complexity in pharmaceutical RL [67]. A review was conducted on the development and implementation of the pharmaceutical reverse logistics system in 28 hospital units in the UK [68]. The authors recommended that enhancing Reverse Logistics (RL) in the collection of unused and expired drugs would result in substantial financial savings and operational advantages for the supply chain ecosystem, while also reducing pharmaceutical losses. Furthermore, a general framework for defining the RACI (Responsible, Accountable, Consulted, and Informed) matrix of each actor of the pharma RL was presented by the author, [69]. The proposal suggests the utilization of a secure information system to streamline the collection of expired drugs within the supply chain. Additionally, a green model for the Humanitarian Pharmaceutical Supply Chain (HPSC) was put forth with the aim of minimizing avoidable pharmaceutical waste and ensuring the appropriate disposal of unavoidable waste [70]. The study highlighted the complexity and costliness of implementing reverse supply chain practices in the HPSC compared to other industries, mainly due to the inability to reuse or resell end-of-life items. In a comprehensive review of reverse logistics in the HPSC, the author [67] addressed limitations and provided recommendations for future research in this field.

2.4. Literature Review of Humanitarian Supply Chain Collaboration

Given the diverse and occasionally conflicting objectives of supply chain partners, there has been substantial investigation into various coordination mechanisms. These mechanisms aim to improve overall profitability at a global level while also protecting the individual profits of each member involved in the supply chain [52]. The literature offers a wide range of studies on coordination mechanisms, particularly through supply chain contracts, that optimize profit and minimize risks or costs, considering economic and environmental considerations[71]. A quantity discount contract was proposed to mitigate the risk of false failure returns and generate cost savings in a two-tier reverse supply chain (Huang, Choi, Ching, Siu, and Huang, [72]). In a different study, a revenue-sharing contract was employed by Zeng [73] to coordinate and optimize the return policy in an electronic product reverse supply chain. The researchers Govindan and Popiuc [22] developed a revenue-sharing contract specifically for collecting, remanufacturing, or recycling end-of-life products in the personal computer industry. In a comprehensive study, Govindan, Popiuc, and Diabat [23] examined coordination contracts in both traditional and reverse supply chains. Furthermore, Guo, Shen, Choi, and Jung [74] conducted a review of contracts within the context of reverse logistics, focusing on channel structures and leadership considerations. The cumulative findings from these studies enhance our comprehension of coordination mechanisms and the significance of contracts in reverse logistics. They offer valuable insights into optimizing profitability, mitigating risks, and addressing environmental considerations within the supply chain. Researchers have examined a unique revenue-sharing mechanism to coordinate a three-tier supply chain, which includes a single manufacturer, multiple distributors, and multiple retailers. The investigation specifically emphasizes the impact on consumer surplus [75]. In another study, collaborative decision-making was examined as a coordination mechanism in a retailer-supplier supply chain dealing with seasonal products and stochastic demand. The objective was to optimize the ordering policy and investment [76].

Additionally, researchers proposed a two-part tariff contract to coordinate a competitive supply chain involving one supplier and two retailers with socially price-sensitive demand [77]. The author Viegas [78] conducted a comprehensive review of reverse Supply Chains and highlighted the limited attention given to humanitarian activities within this chain despite numerous studies focusing on the environmental and economic aspects. Managing supply chains that combine environmental and humanitarian dimensions poses a significant challenge in today's economy [79]. The humanitarian activities, which present a challenge for decision-makers, encompass voluntary activities related to various aspects such as human rights, community, philanthropy, workplace, and the environment [80]. The concept of social activities as another dimension of sustainability has been explored in different fields with varying interpretations [75]. However, research on humanitarian activities in the pharmaceutical industry, which plays a crucial role in ensuring patient/customer service levels in PSCs, remains limited [81]. To address this research gap, a model [76] was proposed that considers a high customer service level indicator in a two-tier pharmaceutical supply chain. The researchers explored collaborative economic and social models to optimize decision-making related to the supplier's visit intervals and the retailer's replenishment policy. They investigated a coordination mechanism specifically designed for a two-tier supply chain, where the supplier assumes responsibility for humanitarian activities. This model was specifically applicable to items with seasonal sales, fixed shelf-life, and uncertain demand, such as medications. Researchers investigated the development of sustainable performance within a two-tier pharmaceutical supply chain through the implementation of Corporate Social Responsibility (CSR) practices [32]. They presented a multi-objective coordination scheme using a periodic review replenishment model, aiming to make optimal decisions regarding visit intervals and the safety stock factor. In a study by Tat et al. [79], a ship-back scheme was introduced to promote donation activities in the supply chain. They proposed a customized revenue and cost-sharing contract as a coordination mechanism.

2.5. Research Gap

Considering the wealth of research conducted on different managerial aspects within the pharmaceutical industry, relatively limited attention has been given to analytical and mathematical inventory models specifically targeting sustainable solutions in Humanitarian Pharmaceutical Supply Chains (HPSCs). Building upon the works of Modak [75], Tat et al. [52] and Zeng [73], this study introduces a ship-back concept applied to the HPSC to collect the excess medications before they become outdated.

This paper makes a unique contribution to the existing literature on pharmaceutical sustainability by introducing a novel "two-level donation" strategy that effectively addresses both the economic and environmental dimensions. It also proposes a bi-level optimization collaborative scheme to coordinate the efforts within a three-echelon HPSC that experiences uncertain demand.

3. HPSC Problem Statement and Formulation

A three-echelon Humanitarian supply chain model, comprising PC, LHLP, and RHLP, is set up. The forecast trend is perceived as dynamic. Initially, the PC proactively engages in donation funding in collaboration with the Global Alliance (GA). The PC invests in sustainable activities and assumes the role of the leader of the humanitarian ecosystem. At the start of the distribution season ($t = 0$), the PC announces its decision regarding the quantity of donations (G) to improve medicine access equity. Subsequently, the LHLP, acting as the follower, determines the quantity of medications to be ordered (Q). The demand function is defined taking inspiration from [79]:

$$D = x + D(G)$$

$$D(G) = a\left(1 - \frac{1}{1 + 0{,}1G}\right)$$

$$\frac{a - D(G)}{a} = \left(\frac{1}{1 + 0{,}1G}\right)$$

$$\left(\frac{a}{a - D(G)} - 1\right)/0{,}1 = G$$

$$\boldsymbol{G^{dc} = \frac{1}{0,1}\left(\sqrt{\frac{0,1a(p - \mathbf{c} + \mathbf{b}'')}{(\mathbf{p}' + \mathbf{l})}} - 1\right)}$$

"x" represents the stochastic component of demand, while "a" denotes the demand donation coefficient of PC. Subsequently, to address demand uncertainty and tackle the challenge of excessive medicine wastage, the RHLP conducts scheduled visits to the LHLP inventory during the distribution season (t = t'). During these visits, the RHLP retrieves additional medications (q) based on the realized demand (D_t). If the quantity of ship-back inventory is equal to or lower than the initially determined donation volume, it is considered part of the announced donation. If the quantity of ship-back inventory exceeds the initially determined donation amount at the beginning of the period, the surplus is directed towards the tertiary country. Figure 2 provides a visual representation of the model described, and Figure 3 shows the decision variable owners.

3.1. Roles & Responsibilities of the Global Alliances (GA)

- Establish the humanitarian network and supply mechanism.
- Provide compensation and motivation to the involved members to ensure the achievement of humanitarian goals.
- Coordinate and facilitate collaboration among different stakeholders.
- Implement stockout penalties for PC, RHLP and LHLP.

3.2. Roles & Responsibilities of the Pharma Companies

- The PC is actively participating in the donation efforts alongside the global alliance.
- Collaborate with the RHLP to develop a humanitarian forecast.
- Enhance collaboration with healthcare providers.
- Generate donation orders.
- Monitor and optimize the inventory within the humanitarian network.
- Manage the disposal process for expired medicines.

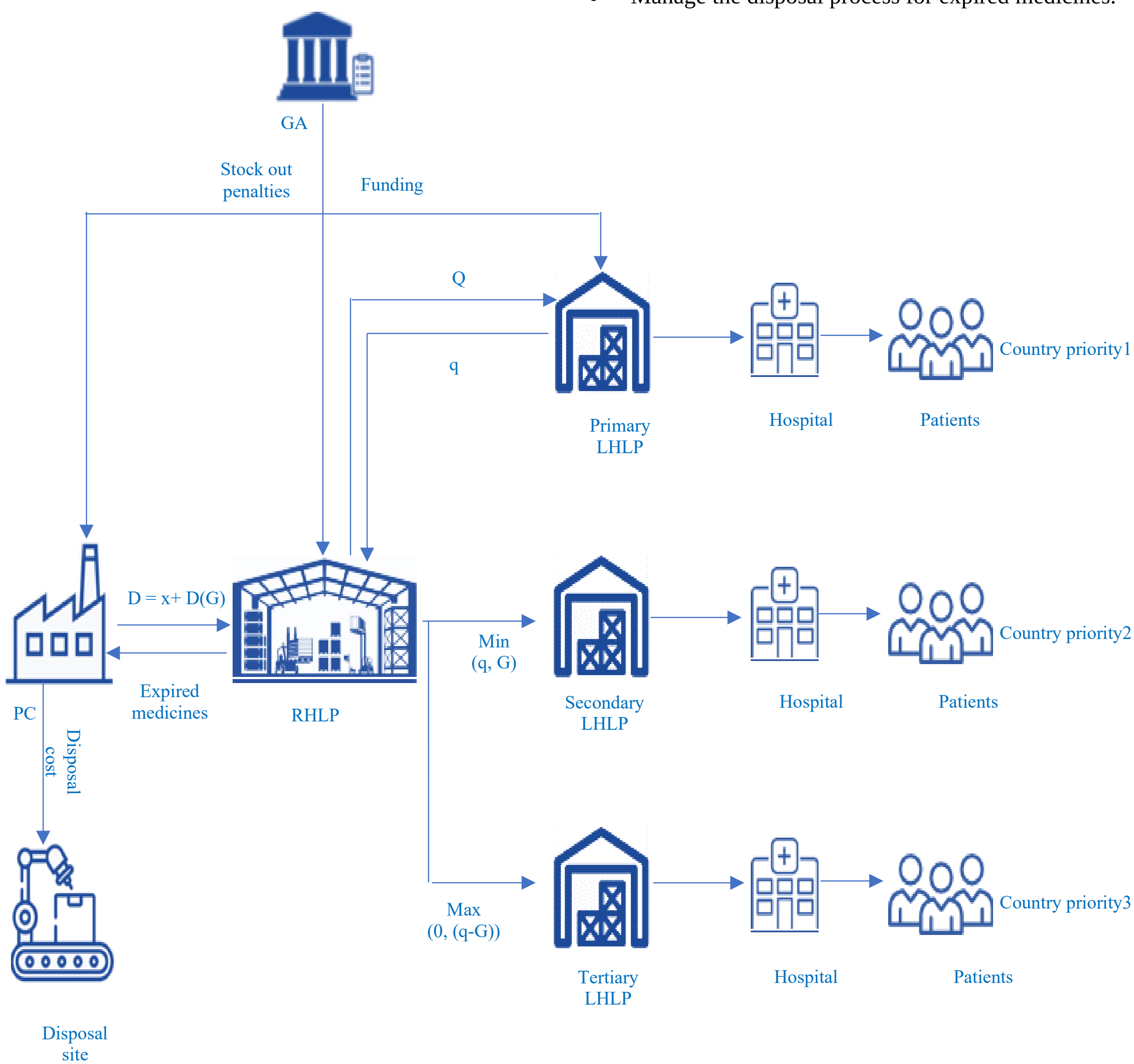

Fig. 2 Proposed HPSC model

		PC	RHLP	LHLP
Decision variables	G	x		
	Q			x
	q		x	

Fig. 3 HPSC decision variable

3.3. Roles and Responsibilities of the RHLP

The regional humanitarian logistic provider has crucial roles and responsibilities in optimizing resources and improving collaboration in humanitarian operations.

- Collaborate with the PC to develop a humanitarian forecast.
- Manage the storage, transportation, and distribution of humanitarian inventory.
- Manage the allocation of inventory across the network of recipient countries.
- Facilitate collaboration and coordination among multiple stakeholders.
- Take charge of the reverse logistics process from the LHLP and redistribute any remaining inventory to alternative countries.
- Arrange for the shipment of expired drugs back to the PC and cover the associated disposal costs.

3.4. Roles and Responsibilities of the LHLP

- Give the green light to deliver the orders based on the agreed schedule.
- Share the inventory update with PC and RHLP following a predefined calendar.
- Manage all local logistic functions (transport, customs clearance, product local release, warehousing, distribution…).
- Ensure the distribution of the humanitarian order among the network of local hospitals and associations.
- Contribute to the reverse logistic process.

3.5. Scientific Notations

The scientific notations used are listed in Table 1. The exhibitor's "dc", "c" and "co" denote the game theory' model (decentralized, centralized and cooperative), respectively.

3.6. Abbreviation

PC	Pharma Company
LHLP	Local Humanitarian Logistic Provider
RHLP	Regional Local Humanitarian Logistic Provider
HPSC	Humanitarian Pharmaceutical Supply Chain
GA	Global Alliance
UP	Uniform Probability

4. HPSC Mathematic Model Description

This section focuses on formulating the profit functions of the actors within the Humanitarian Pharmaceutical Supply Chain (HPSC) and determining the optimal decisions for variables G, Q, and q in both decentralized and centralized decision-making scenarios. Subsequently, a collaboration scheme is developed in the form of an optimization collaborative model. The aim is to achieve a win-win approach that benefits all HPSC stakeholders while optimizing the overall profit of the entire HPSC.

4.1. Decentralized Approach

In the decentralized approach, the actors independently make decisions to optimize their individual profits without considering the profitability of other members. In this structure, the pharmaceutical company, acting as the leader, first determines the amount of donation at time t = 0.

Then, the Local Humanitarian Logistic Provider (LHLP) makes decisions regarding its own order quantity. Finally, the Regional Humanitarian Logistic Provider (RHLP) determines the ship-back quantity based on the realized demand at t = t'. Equation (1) represents the pharmaceutical companies' Expected Profit Function at time t = 0.

$$\mathrm{E}\left(\mathrm{R}_p^{dc}(G)\right) = (\mathrm{p}-\mathrm{c})\mathrm{Q} - (\mathrm{p}'+\mathrm{l})\min(q,\mathrm{G}) + \Theta\mathrm{E}[\max(0,(\mathrm{Q}-\mathrm{D}_{\mathrm{t=0}})] - \mathrm{b}''\mathrm{E}[\max(0,\mathrm{D}_{\mathrm{t=0}}-\mathrm{Q})] \quad (1)$$

Following mathematical development, the equation is derived. (see demonstration 1 in the appendix):

$$\mathrm{E}\left(\mathrm{R}_p^{dc}(G)\right) = (\mathrm{p}-\mathrm{c}+\mathrm{b}'')\mathrm{Q} - (\mathrm{p}'+\mathrm{l})q + (\mathrm{p}'+\mathrm{l})\max(0,(\mathrm{q}-\mathrm{G}))) + (\Theta-\mathrm{b}'')\int_{-\infty}^{Q}(Q-D)f_P(x)d(x) - \mathrm{b}''(E(x)) \quad (2)$$

In Equation (1), the initial sentence denotes the sales revenue of the PC. The second sentence pertains to the purchasing cost of the donation quantity from GA and the transportation cost from RHLP to the secondary country. The subsequent sentence indicates the disposal cost received from RHLP. The final sentence describes the stockout penalties. The expected profit function of the pharmaceutical company at the start of the time-cycle exhibits concavity with respect to the variable G, and the optimal value is obtained as follows:

$$\boldsymbol{G^{dc}} = \frac{\mathbf{1}}{\mathbf{0,1}}\left(\sqrt{\frac{\mathbf{0,1}\boldsymbol{a}(\boldsymbol{p}-\mathbf{c}+\mathbf{b}'')}{(\mathbf{p}'+\mathbf{l})}} - \mathbf{1}\right) \quad (3)$$

See demonstration 2 in the appendix

The expected profit function of the pharmaceutical company at the appointed ship-back time in Equation (4) is formulated similarly to Equation (1). Due to the uncertainty of demand, it is not possible to accurately predict demand at t = 0. The realized demand at t = t′ ($\mathbf{D}_t$) is distinct from the demand predicted at time t = 0 (D).

$$\mathrm{E}\left(\mathrm{R}_p^{dc}(G)\right) = (\mathrm{p}-\mathrm{c})\mathrm{Q} - (\mathrm{p}'+\mathrm{l})\min(q,\mathrm{G}) + \Theta\mathrm{E}\left[\max\left(0,(\mathrm{Q}-\mathrm{D}_{\mathrm{t=t'}})\right)\right] - \mathrm{b}''\mathrm{E}[\max(0,\mathrm{D}_{\mathrm{t=t'}}-(\mathrm{Q}-\mathrm{q})] \quad (4)$$

Table. 1 List of the parameters used in the model Notations, parameters and decision variables

Parameters	
T	Time cycle [0, T]
t′	The appointed reverse logistic time (0≤ t′<T)
c	The production cost per unit
h	The holding cost per excess unit LHLP
p	The unit price of Q (GA to PC)
p’	The unit price of G (PC to GA)
L	Logistic cost of G to secondary country
r_l	Remuneration value (GA to LHLP) for Q
r_r	Remuneration value (GA to RHLP) for Q
£	Rework cost supported by HHLP
θ	Disposal cost for each expired medicine unit
τ	The transportation cost to tertiary country
β	Reverse logistic cost of q
b	LHLP shortage cost
b'	RHLP shortage cost
b"	PC shortage cost
D	Demand of the pharma-retailer at t = 0
x	The random part of demand at t = 0 that follows probability density function f(x) and cumulative probability function F(x)
a	The donation coefficient
D_t	Realized demand at the appointed ship-back time
x_t	The random part of demand at the ship-back time that follows f (x_t) and F (x_t)
Decision	variables
Q	LHLP order quantity
G	PC donation quantity
q	RHLP ship-back quantity
Coordination	model variable
Ω	% Sharing increase rate given from GA to PC
α	% Sharing revenue of PC with LHLP & RHLP
B, B’, B’’	New shortage penalties of LHLP, RHLP & PC
Financial	Parameters
$E(R_L(Q))$	LHLP expected revenue function
$E(R_p(G))$	PC expected revenue function
$E(R_r(q))$	RHLP expected revenue function
$E(R_{sc}(Q,G,q))$	Total HPSC expected revenue function

After similar mathematic development as Equation (1), the result is obtained:

$$E\left(R_p^{dc}(G)\right) = (p - c + b'')Q - (p' + l + b'')q + (p' + l)\max(0,(q - G))) + (\Theta - b'')\left(\int_{-\infty}^{Q-q}(Q-q)f_D(x)d(x) - \int_{-\infty}^{Q-q} D_t\, f_D(x)d(x)\right) - b''(E(x) + D(G)) \tag{5}$$

The expected profit function of the LHLP at the beginning of the time cycle is formulated as:

$$E\left(R_l^{dc}(Q)\right) = r_l E[\min(Q, D_{t=0})] - hE[\max(0, Q - D_{t=0})] - bE[\max(0, D_{t=0} - Q)] \tag{6}$$

After similar mathematic development as Equation (1), the result is obtained:

$$E\left(R_l^{dc}(Q)\right) = Q(r_l + b) - bE - (r_l + h + b)\int_{-\infty}^{Q}(Q - D)f_D(x)d(x) \tag{7}$$

In Equation (6), the initial sentence denotes the remuneration obtained from GA for each unit distributed locally. The subsequent sentence expresses the holding cost of leftover items. The following sentence pertains to the stockout penalty. The LHLP expected profit function is concave in Q, and the optimal order quantity is:

$$\mathbf{Q}^{dc} = \mathbf{F_D^{-1}}\left(\frac{r_l+\mathbf{b}}{r_l+h+b}\right) + \boldsymbol{D(G)} \qquad (8)$$

See demonstration 3 in the appendix.

The LHLP expected profit function at t=t' is expressed as follows:

$$\mathrm{E}\left(\mathrm{R}_l^{dc}(Q)\right) = r_l \mathrm{E}[\min((\mathrm{Q}-\mathrm{q}), \mathrm{D}_{\mathrm{t=t'}})] - \mathrm{hE}[\max(0, (\mathrm{Q}-\mathrm{q}) - \mathrm{D}_{\mathrm{t=t'}})] \qquad (9)$$

After a similar mathematic development as Equation (1), the result is obtained:

$$\mathrm{E}\left(\mathrm{R}_l^{dc}(Q)\right) = r_l Q - (\mathrm{h}+r_l)\left(\int_{-\infty}^{Q-q} (Q-q) f_D(x) d(x) - \int_{-\infty}^{Q-q} D_t\, f_D(x) d(x)\right) \qquad (10)$$

The first two sentences of the expected profit function of the LHLP at t=t' in Equation (9) are formulated similarly as in Equation (6). However, the final term of the stockout penalty has been eliminated since the responsibility for the ship-back quantity q falls under RHLP. The expected profit function of the RHLP at the beginning of the time cycle is formulated as follows:

$$\mathrm{E}\left(\mathrm{R}_r^{dc}(q)\right) = r_r \mathrm{Q} + \beta \mathrm{q} - (£ - \mathrm{l})\min(q, \mathrm{G}) + \tau \max(0, (\mathrm{q}-\mathrm{G})) - \Theta \mathrm{E}[\max(0, (\mathrm{Q} - \mathrm{D}_{\mathrm{t=0}})] \qquad (11)$$

After a similar mathematic development as Equation (1), the result is obtained:

$$\mathrm{E}\left(\mathrm{R}_r^{dc}(q)\right) = r_r \mathrm{Q} + \beta \mathrm{q} - (£ - \mathrm{l})\min(q, \mathrm{G}) + \tau \max(0, (\mathrm{q}-\mathrm{G})) - \Theta \int_{-\infty}^{Q} (Q-D) f_D(x) d(x) \qquad (12)$$

Where the first sentence in Equation (11) shows the revenue of the RHLP by shipping Q to LHLP, the second sentence expresses reverse logistic revenue of the returned quantity q. The third sentence determines the rework cost and the transportation price received from PC for the donation quantity. The fourth term expresses the transportation price to the tertiary country, and the last term indicates the destruction cost that RHLP is paying to PC in case of destruction operation of the expired medication. The expected profit function of the RHLP at t=t' is formulated as:

$$\mathrm{E}\left(\mathrm{R}_r^{dc}(q)\right) = r_r \mathrm{Q} + \beta \mathrm{q} - (£ - \mathrm{l})\min(q, \mathrm{G}) + \tau\max(0, (\mathrm{q}-\mathrm{G})) - \Theta \mathrm{E}[\max(0, (\mathrm{Q} - \mathrm{D}_{\mathrm{t=t'}})] - \mathrm{b'}\mathrm{E}[\max(0, \mathrm{D}_{\mathrm{t=t'}} - (\mathrm{Q}-\mathrm{q}))] \qquad (13)$$

After a similar mathematic development as Equation (1), the result is obtained:

$$\mathrm{E}\left(\mathrm{R}_r^{dc}(q)\right) = r_r \mathrm{Q} + (\beta - £ + \mathrm{l} + \mathrm{b'})q + (£ - \mathrm{l} + \tau + \mathrm{b'})\max(0, (\mathrm{q}-\mathrm{G})) - \mathrm{b'}\left(E(x) + \mathrm{D(G)}\right) - (\Theta + \mathrm{b'})\left(\int_{-\infty}^{Q-q} (Q-q) f_D(x) d(x) - \int_{-\infty}^{Q-q} D_t\, f_D(x) d(x)\right) \qquad (14)$$

The expected profit function, Equation (13), is nearly identical to the expected profit function, Equation (11), with the exception that the last term for the stock out penalty has been transferred from LHLP to RHLP. The RHLP EPF is concave in q, and the optimal order quantity is:

$$\mathbf{q}^{dc} = \mathbf{Q} - \mathbf{F_D^{-1}}\left(\frac{\boldsymbol{\tau}-\boldsymbol{\beta}}{\boldsymbol{\Theta}-\mathbf{b'}}\right) - \boldsymbol{D(G)} \qquad (15)$$

See demonstration 4 in the appendix.

4.2. Centralized Approach

The objective of the centralized decision-making structure is to optimize the overall performance of the entire humanitarian supply chain. In this structure, the decision variables are adjusted to maximize the profitability of the entire channel. As mentioned in the previous subsection, the model under consideration is analyzed at two distinct decision points. Thus, to determine the decision variables "Q, G and q" the centralized structure is formulated for both specific decision times, namely t = 0 and t = t'. Equation (16) represents the expected profit function of the HPSC at the decision point t = t'. It's the combination of the expected profit function of the PC, LHLP and RHLP.

$$\mathrm{E}\left(\mathrm{R}_{sc}^{c}(Q,G,q)\right)_{t=t'} = \mathrm{E}\left(\mathrm{R}_p^{dc}(G)\right)_{t=t'} + \mathrm{E}\left(\mathrm{R}_l^{dc}(Q)\right)_{t=t'} + \mathrm{E}\left(\mathrm{R}_r^{dc}(q)\right)_{t=t'} \qquad (16)$$

$$\mathrm{E}\left(\mathrm{R}_{sc}^{c}(Q,G,q)\right)_{t=t'} = (\mathrm{p} - \mathrm{c} + r_r + \mathrm{b'} + \mathrm{b''} + r_l)\mathrm{Q} - (\mathrm{p'} - \beta + £ + \mathrm{b'} + \mathrm{b''} + r_l)q + (\mathrm{p'} + £ + \tau)\max(0, (\mathrm{q}-\mathrm{G})) - (\mathrm{b'}+\mathrm{b''})(\mathrm{E(x)} + \mathrm{D(G)}) - (r_l + \mathrm{h} + \mathrm{b'} + \mathrm{b''})\left[\int_0^{(Q-\mathrm{q})-\mathrm{D(G)}} (Q-\mathrm{q}) f(x) dx - \int_0^{(Q-\mathrm{q})-\mathrm{D(G)}} (x + \mathrm{D(G)}) f(\mathrm{x}) d\mathrm{x}\right] \qquad (17)$$

The Expected Profit Function of the total channel at t = t′ is concave with respect to the variable q, and the optimized quantity q^c, which maximizes the expected profit, can be determined as follows:

$$\mathrm{q}^c = \mathrm{Q} - D(G) - \mathrm{F}_{\mathrm{D}_{\mathrm{t=t'}}}^{-1}\left(\frac{2\mathrm{p'} + 2£ + \mathrm{b'} + \mathrm{b''} + r_l + \tau - \beta}{r_l + \mathrm{h} + \mathrm{b'} + \mathrm{b''}}\right) \qquad (18)$$

See demonstration 5 in the appendix.

Equation (19) indicates HPSC's expected profit at the beginning of the time cycle calculated from the sum of the profit of the channel members at t =0.

$$E\left(R_{sc}^{c}(Q,G,q)\right)_{t=0} = E\left(R_{p}^{dc}(G,q)\right)_{t=0} + E\left(R_{l}^{dc}(Q)\right)_{t=0} + E\left(R_{r}^{dc}(Q,q)\right)_{t=0} \quad (19)$$

$$E\left(R_{sc}^{c}(Q,G,q)\right)_{t=0} = (p - c + r_r + r_l + b'' + b)Q - (b'' + b)(E(x) + D(G)) - (p' + £ - \beta)q + (p' + £ + \tau)\max(0,(q-G)) - (r_l + h + b + b'')\left[\int_0^{Q-D} Qf(x)dx - \int_0^{Q-D}(x + D)f(x)dx\right] \quad (20)$$

The expected profit function of the total chain at the start of the time cycle exhibits concavity with respect to the variables G and Q. The optimal values for the order quantity and donation volume that maximize the expected total chain profit at time t = 0 can be obtained as follows:

$$\boldsymbol{Q^c = F_D^{-1}\left(\frac{p-c+r_r+r_l+b''+b}{r_l+h+b+b''}\right) + D(G)} \quad (21)$$

M is considered defined as $M = F_D^{-1}\left(\frac{p-c+r_r+r_l+b''+b}{(r_l+h+b+b'')}\right)$

$$G^c = \frac{\sqrt{\frac{0{,}1a}{(p'+£+\tau)}((r_l+h+b+b'')M - b'' - b) - 1}}{0{,}1} \quad (22)$$

See demonstration 6 in the appendix.

4.3. Cooperative Approach

In order to enhance individual profits, the centralized decision-making model is designed to maximize the overall profitability of the entire supply chain. However, it is crucial to ensure that the profitability of all members is not adversely affected in the process. If a decision does not bring benefits to all supply chain members, they may refuse to accept it. Various coordination contracts, such as revenue-sharing contracts, buyback contracts, quantity discount contracts, and two-part-tariff contracts, have been developed in both forward and reverse supply chains to incentivize members to make centralized decisions [23]. In this section, a bi-level optimization collaboration model is introduced to encourage member participation in channel optimization and facilitate the coordination of decisions related to the PC's donation quantity determined at the start of the sales season, the LHLP's order quantity at time t = 0, and the RHLP's ship-back quantity at time t = t'. A mathematical model is formulated to maximize the overall benefit of the Humanitarian Pharmaceutical Supply Chain (HPSC) and coordinate the decisions within the channel. This model is specifically adjusted to ensure that the three HPSC members can generate profits.

In the proposed model, switching from decentralized to centralized decision-making will worsen off the profitability of the LHLP & RHLP, so the PC and GA are required to apply a proper incentive coordination model to motivate both logistic providers to participate in the plan and increase the stockout penalties amount. In this section, a customized revenue is presented to attain HPSC coordination. The terms of the coordination contract introduced by the PC & GA are as follows:

- α : Contractual Fixed incentive given by PC. It's allocated by unit distributed in the primary country, and it's shared between LHPL (50%) and RHLP (50%). The objective is to create synergy between both parties.
- Ω : The GA offers % of increase in PC price to support the PC to lead the ecosystem.
- B: The GA increased the stockout penalties for the LHLP. The objective is to balance with the extra incentive given.
- B': The GA increased the stockout penalties for the RHLP. The objective is to balance with the extra incentive given.
- B": The GA increased the stockout penalties for the PC. The objective is to balance with the extra incentive given.
- β_c : The GA offers a new ship-back price to RHLP. The objective of this parameter is to motivate the RHLP to collect the excess stock before expiration so that it can be redistributed to the alternative country and avoid drug destruction.

PC undertakes to decide the medicine donation quantity as the same as the centralized structure ($G_{co} = G_c$) and the GA offers a new ship-back price (β_c). The LHLP profit under the coordination contract at t = 0 can be as follows:

$$E\left(R_l^{co}(Q)\right) = (r_l + (\alpha/2)p)E[\max(Q, D_{t=0})] - hE[\max(0, Q - D_{t=0})] - BE[\max(0, D_{t=0} - Q)] \quad (23)$$

$$E\left(R_l^{co}(Q)\right) = (r_l + (\alpha/2)p + B)Q - B(E(x) + D(G)) - (r_l + (\alpha/2)p + h + B)\int_{-\infty}^{Q}(Q - D)f_D(x)d(x) \quad (24)$$

The LHLP expected profit function is concave in Q, and the optimal order quantity is:

$$Q^{co} = F_D^{-1}\left(\frac{r_l+(\alpha/2)p+B}{(r_l+(\alpha/2)p+h+B}\right) + D(G) \quad (25)$$

The RHLP profit under the coordination contract at t = t' can be as follows:

$$E\left(R_r^{co}(q)\right) = r_r Q + \left(\frac{\alpha}{2}\right)pE[\max(Q - q, D_{t=t'})] + (\beta_c - £ + l)q + (£ - l + \tau)\max\left(0,(q-G)\right) - \theta E[\max(0,(Q - D_{t=t'}) - q)] - B'E\left[\max\left(0, D_{t=t'} - (Q - q)\right)\right] \quad (26)$$

The RHLP expected profit function is concave in Q, and the optimal order quantity is:

$$\boldsymbol{q^{co} = Q - D(G) - F_{D_{t=t'}}^{-1}\left(\frac{\beta_c - (\alpha/2)p - B' + \tau}{(\alpha/2)p + B' + \theta}\right)} \quad (27)$$

The PC profit under the coordination contract at t = 0 can be as follows:

$$E\left(R_p^{co}(G)\right) = (p(1+\Omega) - c)Q - (p' + l)q + (p' + l)\max(0,(q-G))) + \theta E[\max(0,(Q - D_{t=0})] - B''E[\max(0, D_{t=0} - Q)] - \alpha pE[\max(Q, D_{t=0})] \quad (28)$$

5. Proof of Concept: Numerical Analysis

The objective of this section is to evaluate the applicability of the proposed mathematical model by examining and analyzing a series of numerical scenarios. Taking into consideration that the humanitarian pharmaceutical forecast is stochastic, a high forecast error demand will be considered at t = 0. Consequently, the uniform probability distribution model is being assessed across three forecast configuration cases. The experimental set of data has been defined and estimated based on real examples taken from global donation reports published by some global health institutions [5] and from the WHO recommendation:

- Pharmaceutical companies usually sell medicines to GHPs with low margins. In some cases, the declared value of a medicine donation should be based on the wholesale price of its generic equivalent in the recipient country[14].
- All costs of international and local transport, warehousing, port clearance, quality testing and appropriate storage and handling should be paid by the donor. The same prices as those in the commercial area are being applied [14].
- Certain pharmaceutical companies might be able to enjoy improved cash flow through an enhanced tax deduction for the charitable donation of inventory.
- All drug donations should be based on an expressed need and be relevant to the disease pattern in the recipient country. Drugs should not be sent without prior consent by the recipient[14].
- After arrival in the recipient country, all donated drugs should have a remaining shelf-life of at least one year. An exception may be made for direct donations to specific health facilities[14].

5.1. A Comparative Analysis between the "Decentralized," "Centralized," and "Cooperative" Models: Uniform Distribution Model

In this section, a series of numerical experiments is conducted to evaluate the performance of the proposed model. These experiments aim to understand how the model behaves under different decision-making structures. Due to the unpredictable nature of medication demand, it is challenging to accurately predict patient demand at the time of determining the order quantity (t = 0). Therefore, in this section, the proposed model is examined under a uniform demand probability distribution function to capture different demand scenarios at time t = t'. Three scenarios are explored, considering various behaviors of the mean and variance of these distribution functions. Additionally, sensitivity analyses are performed on two parameters: a (a parameter sensitive to donation coefficient) and Ut (the mean of the stochastic component of the demand distribution function). This comparison helps us understand how the suggested model behaves under different decision-making schemes. The main focus is to examine the behavior of the model and analyse its performance through these numerical studies.

Table 3 presents the numerical outcomes of the proposed model under decentralized, centralized, and coordinated decision-making structures. The results are provided for uniform demand distribution functions, considering different scenarios of demand behavior at time t = t'. The comparison of profits among HPSC members operating under decentralized and centralized decision-making structures, as shown in Tables 3 and 4, reveals interesting insights for the uniform, distinct demand distribution functions. Upon examination, it can be observed that when the centralized decision-making approach is applied, the profitability of the PC, LHLP, and RHLP experiences a decline.

The numerical results demonstrate that the proposed contract leads to a decrease in the optimal order quantity of the LHLP (Q) and an increase in the optimal amount of decision variables for the pharmaceutical supplier (G). Moreover, the profitability of the individual channel members and the overall HPSC is enhanced through the implementation of the suggested customized revenue-sharing contract, as compared to the decentralized model.

In essence, the proposed contract facilitates the coordination of the HPSC and ensures the profitability of all channel members in all experiments conducted. This guarantees that HPSC parties are sufficiently motivated to actively participate in the suggested coordination scheme.

Table 3 provides an overview of the outcomes obtained from running the model using three distinct decision-making approaches. These approaches were applied under the context of uniform probability density functions with varying demand behaviors. By comparing the profitability of the HPSC under decentralized and centralized structures, it becomes evident that joint decision-making has the potential to significantly enhance various aspects. Specifically, it leads to a decrease in LHLP order quantity Q, an increase in the RHLP ship-back quantity q, an increase in the pharmaceutical company donation quantity G, and an increase in the overall profit of the humanitarian channel.

Table. 2 Uniform Probability Model Dataset

Uniform	c	h	p	p'	l	r_l	r_r	£	θ	τ	β	β_c	b	b'	b"	B	B'	B"	a	α	**Ω**	D = U (A, B)		Dr =U (Ar, Br)	
Instance 1	60	10	85	20	2	10	10	1	1,7	1	0,5	3	1	1	1	4,5	5	2	40	5%	20%	110	210	100	150
Instance 2	60	10	85	20	2	10	10	1	1,7	1	0,5	3	1	1	1	4,5	5	2	40	5%	20%	100	200	95	150
Instance 3	60	10	85	20	2	10	10	1	1,7	1	0,5	3	1	1	1	4,5	5	2	40	5%	20%	90	200	100	145

Table. 3 Numeric Proof for "decentralized", "centralized" & "cooperative" models

Uniform		a	Q	E(RL(Q))	E(RL(Q))	q	E(Rr(Q))	E(Rr(Q))	G	E(Rp(Q))	E(Rp(Q))	E(Rsc(Q,G,q))	E(Rsc(Q,G,q))
Decentralized	**T1**	40	184	1 289	1 183	27	1 807	1 671	12	4 363	4 375	7 459	7 229
	T2	45	184	1 289	1 183	27	1 807	1 671	12	4 363	4 375	7 459	7 229
	T3	50	184	1 289	1 183	27	1 807	1 671	12	4 363	4 375	7 459	7 229
Centralized	**T1**	40	171	1 146	1 052	32	1 679	1 575	27	3 714	3 721	6 539	6 349
	T2	45	171	1 146	1 052	32	1 679	1 575	27	3 714	3 721	6 539	6 349
	T3	50	171	1 146	1 052	32	1 679	1 575	27	3 714	3 721	6 539	6 349
Cooperative	**T1**	40	168	1 243	1 307	36	1 997	1 700	27	5 809	5 829	9 050	8 836
	T2	45	168	1 243	1 307	36	1 997	1 700	27	5 809	5 829	9 050	8 836
	T3	50	168	1 243	1 307	36	1 997	1 700	27	5 809	5 829	9 050	8 836

Table. 4 Numeric Analysis of "decentralized", "centralized" & "cooperative" models

Uniform		Kept quantity	% of Return	Saving ($)	Cost Avoidance ($)
Decentralized	**T1**	157,32	14%	2 267	45
	T2	157,32	14%	2 267	45
	T3	157,32	14%	2 267	45
Centralized	**T1**	139,36	18%	2 685	54
	T2	139,36	18%	2 685	54
	T3	139,36	18%	2 685	54
Cooperative	**T1**	131,66	22%	3 069	61
	T2	131,66	22%	3 069	61
	T3	131,66	22%	3 069	61

By actively participating in sustainable activities and implementing a ship-back scheme to collect surplus medications before they become outdated, the profitability of the entire HPSC can be increased. This approach not only promotes sustainable practices but also generates additional value for the channel as a whole. Based on the analysis presented in Table 3, it is evident that the centralized model outperforms the decentralized decision-making structure in terms of humanitarian volume optimization. Given these favorable conditions, all channel members exhibit a clear preference for centralized decision-making over the decentralized model.

They recognize the benefits of the integrated structure and willingly adopt the optimal values it offers. This highlights the effectiveness and desirability of the centralized approach in enhancing the optimal variables Q, Q, and G. Nevertheless, it is important to note that centralized decision-making does not ensure benefits for all members of the HPSC compared to decentralized decision-making. The PC, LHLP, and RHLP experience reduced benefits in the integrated model compared to the traditional structure. In such situations, it becomes crucial to establish an appropriate coordination model that ensures the well-being of all HPSC members and provides sufficient motivation for them to embrace the optimal values offered by centralized decision-making.

This coordination model must effectively address the challenges and discrepancies that arise, enabling all members to derive benefits and maintain a harmonious and mutually beneficial relationship within the HPSC. As depicted in Table 4, the adoption of coordination decision-making not only leads to a significant increase in the overall profitability of the entire supply chain but also enhances the individual profitability of the three members in the HPSC. Consequently, the three-channel members are inclined to select the optimal values derived from the coordination model.

Another noteworthy aspect is that the coordination scheme results in lower order quantity Q and higher ship-back and donation amounts compared to the decentralized model. This indicates an increased engagement within the proposed coordination model. As a result, the coordination decision-making structure not only boosts the profitability of the entire chain but also establishes a win-win scenario for all HPSC members, ultimately contributing to the overall improvement of humanitarian activities.

Through the implementation of the cooperative mechanism, a positive synergy between the PC, LHLP, and RHLP has been observed. The numerical analysis conducted demonstrates that the proposed model effectively coordinates the entire humanitarian pharmaceutical supply chain, resulting in increased expected income for all stakeholders. Figures 4 and 5 show that the cooperative model reduced the initial order quantity Q by 9% to optimize the Humanitarian supply chain operations. Additionally, with the adoption of revenue sharing, the expected revenue for the LHLP, RHLP and PC increased respectively by 19%, 16% and 36% . This incentivizes the LHLP to actively engage in the reverse logistics process, leading to a 26% increase in the quantity of returned q and 58% of donation quantity G.

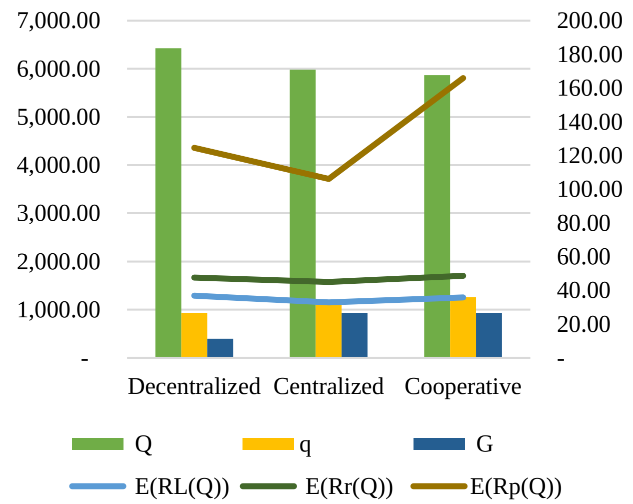

Fig. 4 Optimal variable development impact on the expected profit for each member

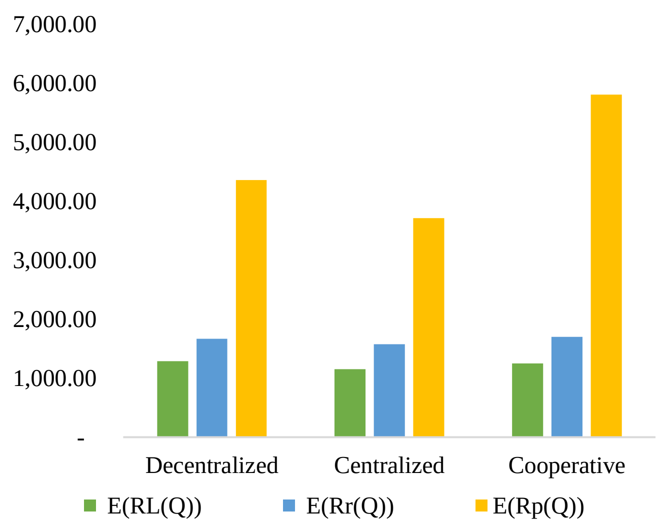

Fig. 5 Expected profits evolution of the PC, LHLP & RHLP

In order to assess the effectiveness of the proposed coordination model, several sensitivity analyses are performed on key parameters. The three scenarios are specifically utilized to examine the impact of varying the donation coefficient parameter (a), the stock out penalty parameter (b/B), and the mean of the demand under the uniform distribution function U_t on the model's performance. These analyses are carried out across three distinct decision-making methods, allowing for a comprehensive evaluation of the model under different conditions.

Figure 6 presents the correlation between the donation coefficient (a) and donation quantity G. As depicted in the figure, and there is a clear trend of increasing medication donations as the parameter (a) increases. This indicates that a higher value of the donation coefficient leads to a greater level of engagement in sustainability practices, specifically in terms of humanitarian inventory management. Furthermore, it is noteworthy that the coordination model exhibits a higher degree of engagement compared to the decentralized model.

This implies that the coordination decision-making structure encourages and facilitates a higher level of involvement in sustainability activities. This highlights the effectiveness of the coordination model in promoting and fostering a greater sense of sustainability within the humanitarian pharmaceutical supply chain.

Figures 7, 8 and 9 show the variations in the overall Profit of the HPSC and the individual channel members as the donation coefficient parameter (a) increases. As anticipated in Figure 5, the profitability of the HPSC is consistently superior under the collaborative decision-making model compared to the other two approaches. Notably, increasing the donation coefficient (a) at both decision points leads to improved profitability for the entire HPSC across decentralized, centralized, and coordination modes.

This indicates that the influence of investing in a sustainability approach is significant, motivating channel members to actively optimize the humanitarian inventory. In Figure 8, it is evident that the RHLP benefit is comparatively lower under the centralized structure at time t = t' when compared to the other decision approaches. In Figure 9, the profitability of the PC in the coordination model surpasses that of the decentralized structure. Furthermore, it is observed that increasing the donation coefficient parameter (a) leads to a rise in the benefit of the PC across various decision structures. Notably, the coordination model consistently ensures higher profitability for the RHLP compared to the decentralized model. This reinforces the effectiveness and reliability of the coordination decision-making model in promoting the financial success of all participants within the supply chain.

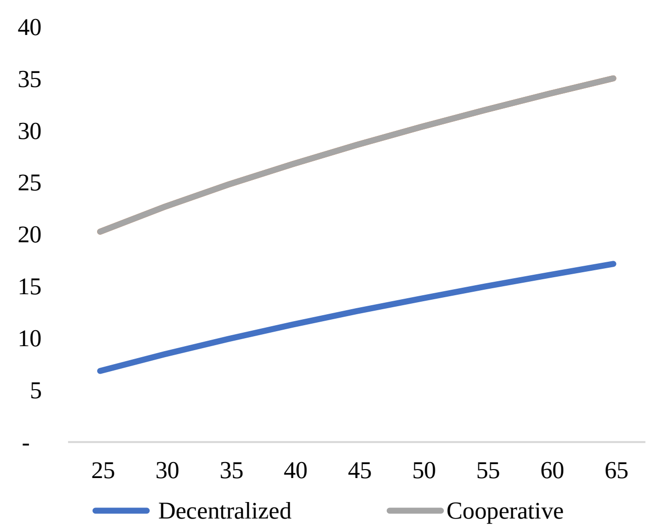

Fig. 6 Impact of donation coefficient on G from decentralized approach to cooperative approach

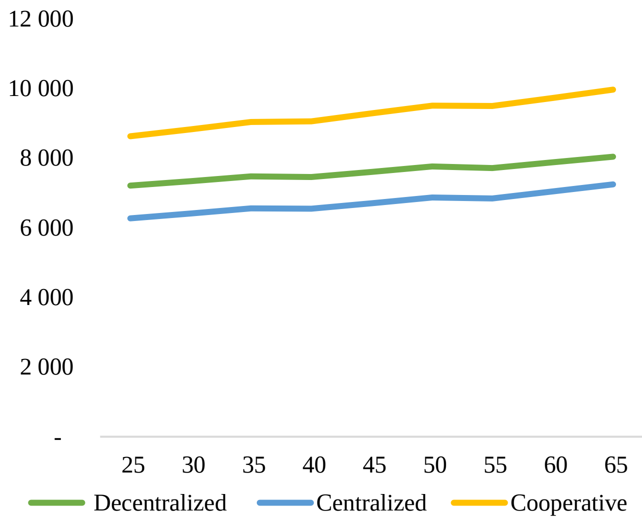

Fig. 7 Impact of donation coefficient on the total profit function of HPSC

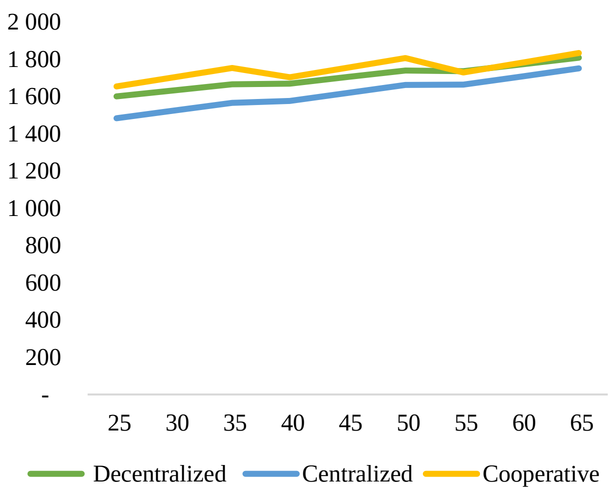

Fig. 8 Impact of donation coefficient on the RHLP profit function

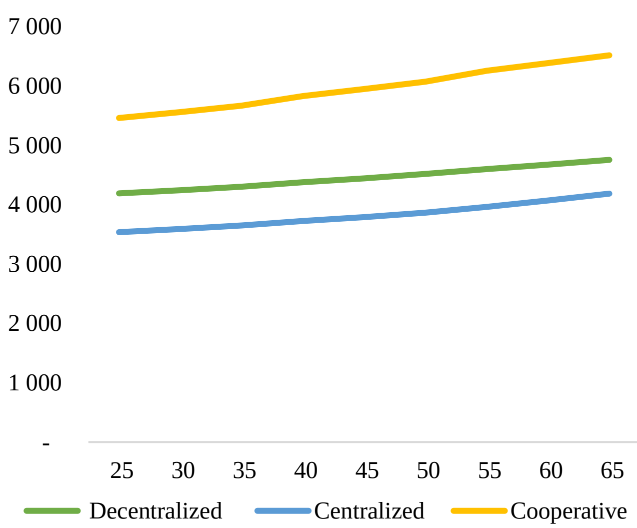

Fig. 9 Impact of donation coefficient on the PC profit function

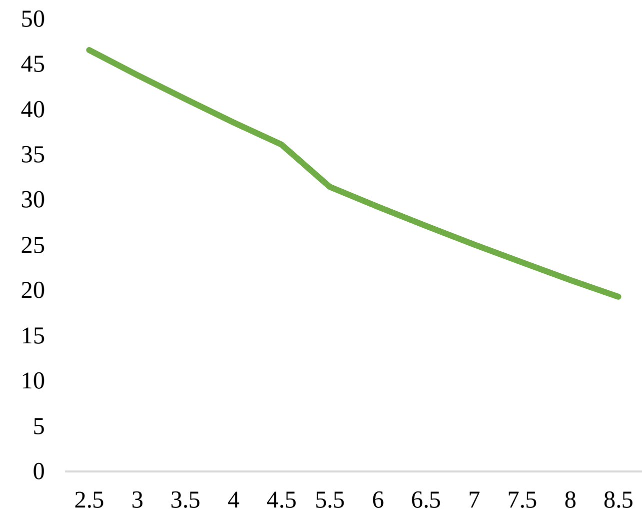

Fig. 10 Impact of the penalty cost of the LHLP on q in the cooperative approach

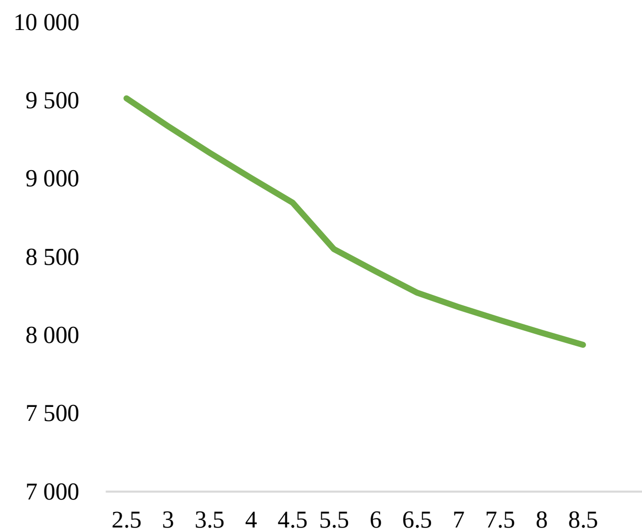

Fig. 11 Impact of the penalty cost of the LHLP on the total HPSC profit in the cooperative approach

Another significant parameter in the proposed model is the penalty imposed by the global alliance to the humanitarian actors for each stock out unit at the end of the period. Thus, the impact of increasing the stock out penalties (B) on the ship-back quantity q is illustrated in Figure 11. As depicted in Figure 11, it can be observed that increasing the penalty parameter results in a reduction in the profitability of the entire humanitarian supply chain across. Figure 12 illustrates the relationship between the mean of the demand distribution function ($\mathrm{U_t}$) and two key decision variables: the quantity of PC donation and the ship-back amount q. As anticipated, when the mean value at time t = t' ($\mathrm{U_t}$) decreases, the quantity q that RHLP retrieves from the LHLP increases. If this ship-back quantity q is equal to or less than the initially determined donation quantity, it is considered part of the announced donation of PC. It is subsequently sent to a secondary country.

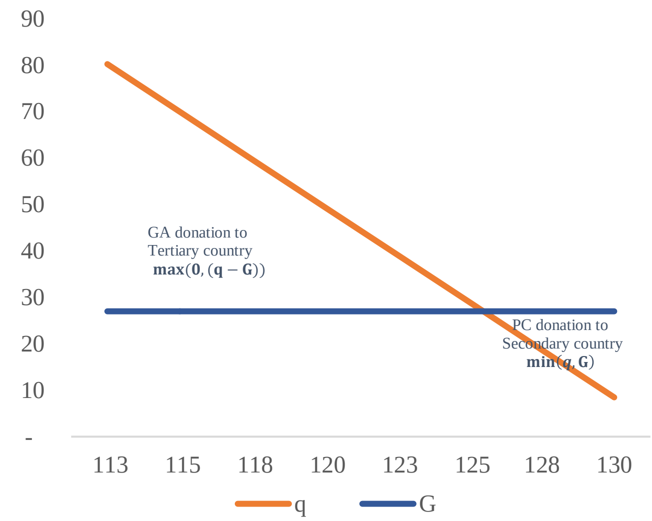

Fig. 12 Evolution in the donation G and ship-back q by shifting U_t in cooperative model

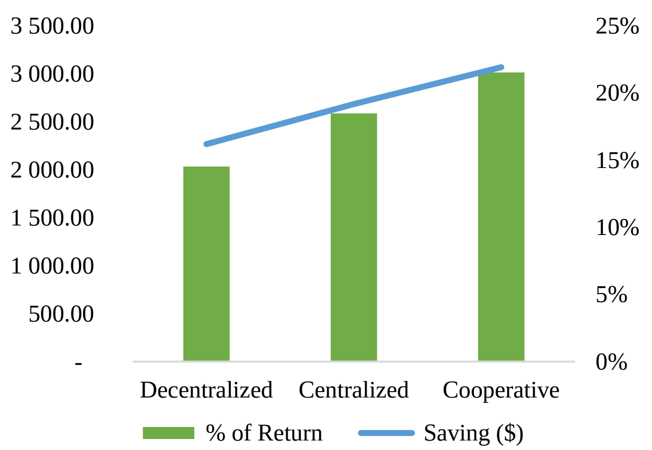

Fig. 13 Saving increase by moving to the cooperative approach

However, if the ship-back quantity exceeds the initially determined donation volume, the surplus items are redirected to the tertiary country to be distributed under the GA contract. It is important to note that where the q-graph surpasses, the G-graph represents the quantity of GA humanitarian donations in the tertiary country. On the other hand, the section where the q-chart falls below the G-chart signifies the amount of inventory that the PC must produce to fulfill the announced donation to the secondary country. In summary, Figure 12 provides a visual representation of the interplay between the mean demand, the PC donation G, and the ship-back quantity q. It demonstrates how fluctuations in these factors impact the surplus items $\max(0, (q - G))$, their allocation, and the actions taken by the PC to maintain the balance between donation G and GA humanitarian activities in the tertiary market.

Figure 13 illustrates that increasing the quantity of returned medications allows for their reallocation to alternative countries, expanding medication coverage to a larger number of patients while reducing the need for producing new quantities. Moreover, redistributing the optimal returned quantity, denoted as q, to alternative countries leads to a doubling of the savings rate. This concept establishes a mutually beneficial relationship between all parties involved. The quantity of medications stored at the country level is reduced by 22% as a result, enabling the RHLP and PC to minimize disposal activities and mitigate the financial impact. This represents a valuable opportunity for cost avoidance within the entire HPSC ecosystem. Ultimately, this mutually beneficial arrangement fosters a WIN-WIN relationship among the Global Alliance (GA), the Pharmaceutical Company (PC), and the local/regional logistics providers. Figures 15 and 16 show that donation cost has a direct consequence on the initial quantity Q and donation volume G. A higher donation cost can result in a decrease in the quantity of donations. The PC may be less inclined to contribute due to the increased cost. Conversely, a lower donation cost can incentivize the PC to participate and contribute, leading to an increase in the quantity of donations.

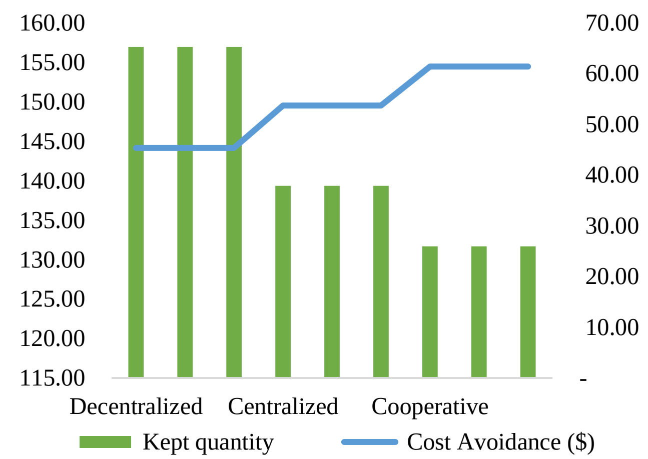

Fig. 14 Cost avoidance increase

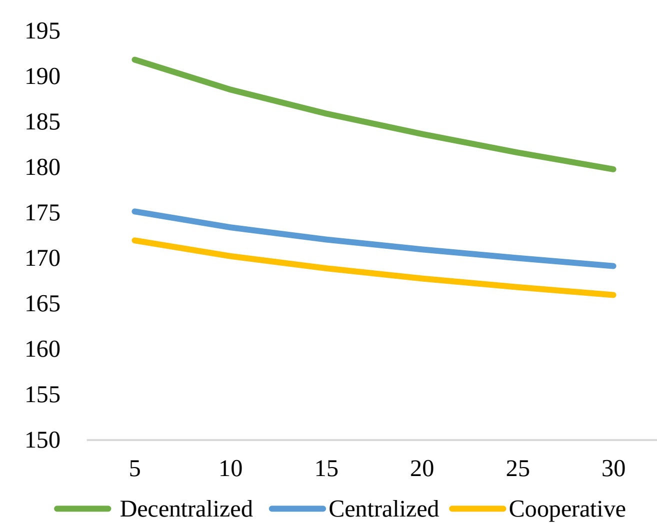

Fig. 15 Impact of the donation price p' on Q

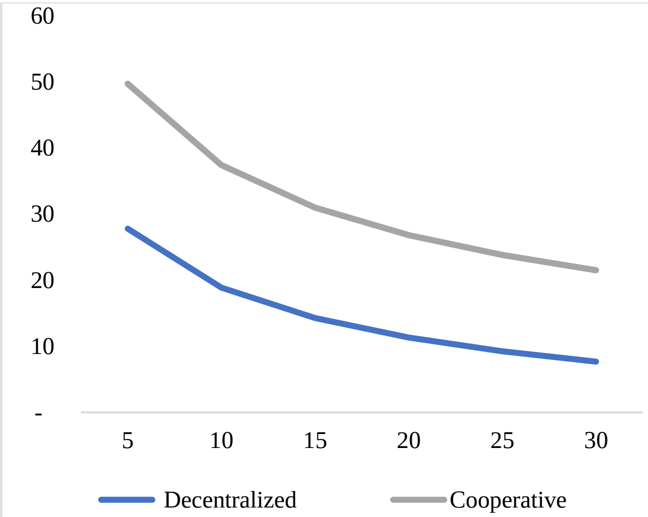

Fig. 16 Impact of the donation price p' on G

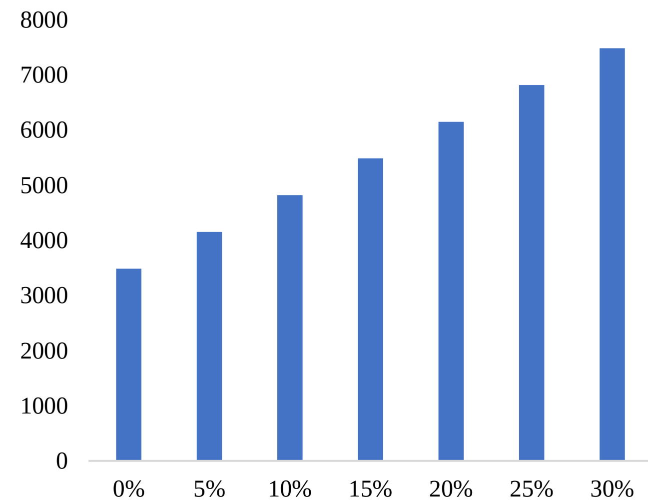

Fig. 17 Impact of the revenue increase Ω on PC expected profit function in the cooperative approach

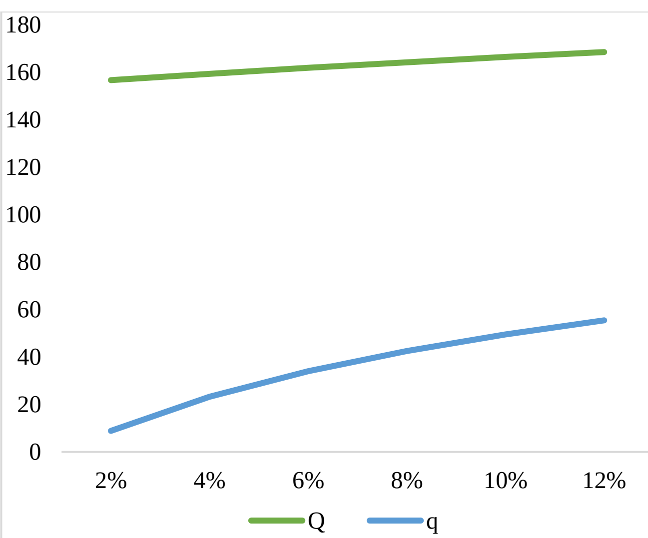

Fig. 18 Impact of the revenue sharing α on Q & q

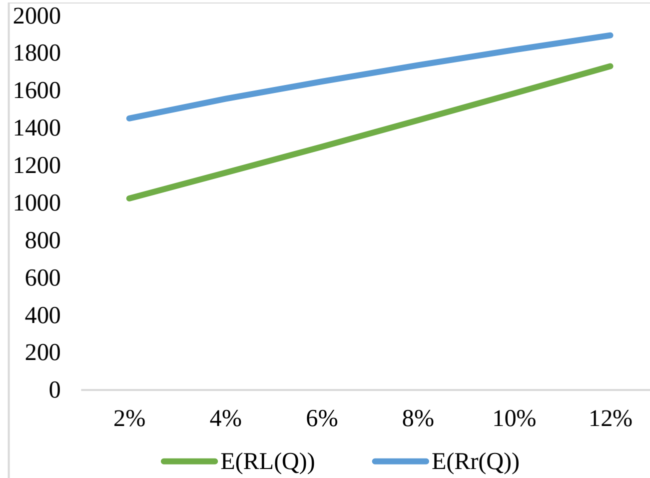

Fig. 19 Impact of the revenue sharing α on the expected profit function of LHLP & RHLP

Figures 17, 18, and 19 demonstrate the direct relationship between the rate of revenue increase and the expected benefit function. The incentive Ω given by the Global Alliance (GA) to the Pharmaceutical Company (PC) positively impacts PC's revenue. By offering greater incentives, the GA motivates the PC to actively engage in and sustain efforts related to humanitarian inventory optimization. Consequently, the PC shares the benefits (Ω) received from the GA with other stakeholders (α), encouraging their acceptance and adherence to the cooperative model. This collaborative effort among stakeholders cultivates a cooperative environment that not only drives revenue growth but also maximizes the overall benefits derived from the implementation of the cooperative approach.

6. Conclusion

This paper aims to effectively coordinate a three-echelon Humanitarian Pharmaceutical Supply Chain (HPSC) while considering the economic objectives. Through a humanitarian contract, the global alliance and its partners agreed to harmonize the donation operations. In this regard, a two-level donation scheme is introduced to optimize the humanitarian inventory. The first level of funding in the HPCS is provided by the global alliance, which distributes the quantity Q to the primary country. The second level of funding is managed by the Pharmaceutical Company (PC), which is responsible for redistributing the remaining quantity q as a donation (G) to the secondary country. In this study, it is assumed that the Regional Humanitarian Logistic Provider (RHLP) periodically visits the inventory of the Local Humanitarian Logistic Provider (LHLP) during the cycle. Surplus medications are retrieved based on the actual demand observed. Following this, the PC determines the allocation of the collected surplus for the announced donation. The introduced cooperative scheme enhances the profitability of each partner and the overall HPSC. It generates significant savings and cost-avoidance opportunities. It effectively tackles the challenges encountered by the HPSC, such as high production costs, coordination problems and medication expiration. Although the proposed model has limitations, future extensions can consider more complex channels with multiple products and varying shelf lives. Additionally, incorporating the LHLP's willingness to return excess medications can further enhance the investigation. Finally, exploring the optimization of the ship-back time as a decision variable rather than a fixed parameter could provide additional insights.

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