Annals of Optimization With Applications

www.anowa.reapress.com

Ann. Optim. Appl. Vol. 1, No. 3 (2025) 182–191.

Paper Type: Original Article

A Fuzzy Logic Transportation Model for Optimizing the Pharmaceutical Supply Chain in Iran

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Citation:

Received: 6 May 2024 *Revised: 22 July 2024* *Accepted: 14 Auguste 2024*	Zarrabi, F., & Hasanpour Jesri, S. O. (2025). A fuzzy logic transportation model for optimizing the pharmaceutical supply chain in Iran. *Annals of optimization with applications, 1*(3), 182-191.

Abstract

The pharmaceutical industry in Iran plays a significant role in the nation's economy. The supply chain in this sector comprises various players, including suppliers of chemicals and packaging materials, as well as retailers that market these products. The structure of this supply chain is quite extensive, encompassing production facilities, storage units, distributors, and wholesalers such as pharmacies, hospitals, and government purchasing centers, along with retailers spread across different regions. This research introduces a transportation strategy specifically for the pharmaceutical industry, with the goal of streamlining logistics operations. The proposed framework takes into account a variety of elements, decision-making variables, and constraints, reflecting the complex dynamics of drug supply networks. To evaluate how well the transportation model performs under uncertain conditions, fuzzy logic techniques are employed. The primary objective is to enhance operational efficiency, lower costs, and improve the overall effectiveness of logistics within the pharmaceutical sector. The results demonstrate the viability and success of the proposed approach in addressing the challenges related to managing transportation in the pharmaceutical field.

Keywords: Pharmaceutical supply chain, Optimization, Transportation model, Fuzzy method, Iran pharmaceutical industry.

1 | Introduction

The pharmaceutical sector is beset with numerous obstacles, primarily due to its extensive and complex supply chains that span multiple locations. This complexity compels enterprises to navigate different indigenous regulations and duty systems. Likewise, effective collaboration with colorful actors in the network, including third-party logistics providers, is essential [1]. Most studies related to pharmaceutical distribution planning examine supply chain operations on a broader level. For illustration, LeBaron [2] bandied a global supply chain strategy for a pharmaceutical establishment and introduced a model designed to optimize product and distribution, with the aim of enhancing net profit. Also, Susarla and Karimi [3] presented a multiperiod mixed-

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https://doi.org/10.48314/anowa.v1i3.49

integer programming model that takes a comprehensive view of sourcing, manufacturing, and distribution. The pharmaceutical supply chain plays a vital role in global healthcare, ensuring that life-saving medications are delivered promptly to patients worldwide. Nevertheless, it encounters a variety of challenges that threaten its effectiveness and responsibility. These difficulties stem from dislocations related to afflictions, geopolitical pressures, and natural disasters, as well as functional hurdles such as managing supply, dealing with counterfeit medicines, and adhering to nonsupervisory norms [4]. For illustration, the COVID-19 epidemic revealed critical sins in supply chain operations, resulting in delays in the delivery of vital supplies and medical supplies. These dislocations punctuate the crucial need for robust and flexible supply chain strategies [5]. Pharmaceutical supply chains are inherently complex, involving a multitude of stakeholders, including manufacturers, distributors, and retailers. This intricacy is enhanced by the global character of these supply chains, which challenge effective collaboration across different regions that differ in regulations, duty structures, and logistical challenges [2].

Likewise, the increase in fake specifics presents a serious threat to community health, underscoring the need for effective verification systems [6]. Dividing these issues demands creative strategies that can manage the essential unpredictability and complications of pharmaceutical supply chains. Fuzzy sense has surfaced as a redoubtable system for defying these obstacles. In discrepancy to conventional models that frequently depend on exact and unchanging data, fuzzy sense embraces vague and private information, making it largely effective for decision-making in uncertain situations [7]. By exercising fuzzy set propositions, decision-makers can assess colorful criteria at present, such as cost, quality, and delivery schedules, to enhance supply chain effectiveness [8]. For instance, fuzzy sense has been effectively employed in supplier assessment, supply control, and transport association, showcasing its flexibility and efficacy in resolving practical supply chain challenges [9]. In a particular study, Uthayakumar and Priyan [10] dived into a supply, product, and distribution dilemma involving several products for a pharmaceutical establishment and a sanitarium supply chain.

Meanwhile, Amaro and Barbosa-Póvoa [11] explored the coupling of product planning and scheduling with rear logistics. Liu and Papageorgiou [12] introduced a multi-objective mixed-integer direct programming system for managing product, distribution, and capacity planning in global supply chains. Still, only a limited number of studies have concentrated on the design of pharmaceutical networks. Amaro and Barbosa-Póvoa [11] addressed the challenges of position, product, and distribution by resolving integrated opinions in two phases for the medicinal and agrochemical sectors. Jalal et al. [13] suggested an acceptable frame for distributing multiple products over a wide range of ages and through different modes of transport. It has also been noted that exploration extends beyond bare thesis testing and data interpretation, with advanced methodologies such as simulation, Artificial Neural Networks (ANN), and fuzzy sense being employed for optimization and decision-making in supply chain operations. Koh and Tan [14] applied fuzzy sense principles to dissect and cover supplier performance grounded on product quality and delivery timelines, while Chiu and Lin [15] demonstrated how cooperative agents and ANNs can synergize to grease collaborative Supply Chain Planning (SCP).

In addition, the combination of fuzzy sense with slice-edge technologies like Artificial Intelligence (AI) and blockchain has significantly expanded its utility in the pharmaceutical supply chain. For illustration, AI-powered predictive analytics can estimate demand and streamline supply operations, while blockchain technology ensures transparency and traceability throughout the supply chain [6]. These inventions not only enhance functional effectiveness but also strengthen the adaptability of supply chains against unexpected disruptions. This paper examines how fuzzy logic can optimize pharmaceutical supply chains, highlighting its ability to enhance effectiveness, reduce costs, and improve decision-making. By examining the specific challenges faced in pharmaceutical logistics, this exploration aims to inform the creation of more flexible and adaptable supply chain strategies. The insights gained from this study are anticipated to provide valuable guidance to industry professionals and policymakers, facilitating the operation of pharmaceutical supply chains while addressing concerns.

2 | Related Literature

The pharmaceutical supply chain is one of the most complex and essential frameworks in the global healthcare landscape. It involves a diverse range of participants, including producers, suppliers, healthcare professionals, and regulatory bodies, all collaborating to ensure that essential items are delivered promptly. However, these supply chains face numerous challenges that can disrupt their functionality. For instance, geopolitical tensions, such as trade disputes and sanctions, can lead to delays in the transportation of both raw materials and finished goods [2]. Similarly, natural calamities and pandemics, such as COVID-19, have exposed vulnerabilities within these networks, resulting in shortages of crucial medications and medical supplies [5].

Most of the literature on pharmaceutical distribution planning concentrates on supply chain strategies comprehensively. Sousa et al. [16] explored a worldwide supply chain for a pharmaceutical firm and introduced a framework designed to optimize product and distribution processes, with the goal of enhancing overall profitability. Susarla and Karimi [17] put forward a multiperiod mixed-integer programming model that takes a global view on procurement, product management, and distribution logistics. In a more focused context, Uthayakumar and Priyan [10] tackled the challenges related to supply, product, and distribution, factoring in multiple products within a pharmaceutical organization and a healthcare supply chain; meanwhile, Amaro and Póvoa [11] investigated how to integrate product planning with scheduling issues, specifically dealing with backorders. Liu and Papageorgiou [18] devised a multi-objective mixed-integer programming approach for planning product distribution and capacity in global supply chains. Conversely, numerous studies have specifically examined the design of pharmaceutical networks [2]. Focused on the positioning, product, and distribution challenges by employing a two-stage integrated approach for both the pharmaceutical and agrochemical industries, [13] proposed a refined model for multi-product, multi-period, and multi-modal distribution planning.

Exploration in the field is not confined to testing hypotheses and analyzing data; it also encompasses more sophisticated methods such as simulation, ANN, and fuzzy logic, which are employed to enhance optimization and decision-making within Supply Chain Management (SCM). In their 2006 study, Koh and Tan applied fuzzy logic principles to evaluate and monitor supplier performance based on criteria such as product quality and delivery timelines. Meanwhile, Chiu and Lin [15] demonstrated how concepts from cooperative agents and ANNs can synergize to facilitate collaborative SCP.

A significant challenge facing the industry is the increasing prevalence of counterfeit products, which not only jeopardizes consumer safety but also undermines the reputation of pharmaceutical manufacturers. According to Mackey [19], counterfeit goods constitute a substantial portion of the global pharmaceutical market, particularly in developing nations. Tackling this issue requires robust tracking and verification systems, such as blockchain technology, to safeguard the supply chain's integrity [20].

Another pressing issue in pharmaceutical supply chains is regulatory compliance. Each nation has its own regulations governing the production, distribution, and sale of medicines, which can lead to delays and increased operational costs. For instance, the European Union's Falsified Medicines Directive mandates that pharmaceutical products undergo stringent reissuing processes, further complicating supply chain operations [2]. These challenges underscore the urgent need for innovative solutions that can effectively navigate the inevitable uncertainties and complexities inherent in pharmaceutical logistics.

2.1 | Fuzzy Logic Applications in Supply Chain Management

Fuzzy logic has become a powerful method for tackling the uncertainties and intricacies found in SCM. Unlike conventional decision-making frameworks, which typically rely on exact and predictable data, fuzzy logic accommodates vague and subjective information, making it a suitable fit for complex systems such as pharmaceutical supply chains [7]. By utilizing fuzzy set theory, decision-makers can simultaneously assess various criteria, including cost, quality, and delivery times, to enhance supply chain operations [8]. A prevalent use of fuzzy logic in SCM is in the evaluation and selection of suppliers. For example, Ferreira [21] illustrated how fuzzy multi-criteria decision-making techniques could rank suppliers based on several factors, like cost, quality, and dependability. This method not only enhances the effectiveness of supplier selection but also improves the overall performance of the supply chain. Fuzzy logic is also applied to inventory management, aiding in navigating uncertainties related to demand prediction and restocking. Priyan [22] developed a fuzzy-stochastic model specifically designed for inventory management in healthcare supply chains, demonstrating its effectiveness in reducing costs while ensuring the continued accessibility of vital medical supplies [22]. Similarly, Bijvank and Vis [23] introduced a fuzzy logic-based strategy for inventory control in hospitals, emphasizing its capability to enhance operational effectiveness in healthcare environments [23]. Beyond supplier evaluation and inventory management, fuzzy logic has been combined with cutting-edge technologies, such as AI and blockchain, to expand its applications. For instance, AI-driven predictive analytics can anticipate demand and fine-tune inventory levels, while blockchain provides transparency and traceability throughout the supply chain [20]. These advancements not only bolster operational efficiency but also strengthen the resilience of supply chains against unexpected disruptions.

2.2 | Sustainability in Pharmaceutical Supply Chains

Sustainability has emerged as an essential factor in SCM, especially within the pharmaceutical sector, where both environmental and social repercussions are under increasing examination. Fuzzy logic has proven to be quite effective in incorporating sustainability measures into supply chain decisions. For instance, a study by Anilkumar and Sridharan [24] introduced a fuzzy multi-criteria decision-making framework aimed at assessing suppliers based on sustainability factors, such as carbon footprint, energy usage, and social accountability. This methodology enables businesses to align their supply chain activities with global sustainability objectives while maintaining operational efficiency. Nonetheless, integrating sustainability into SCM comes with its own set of obstacles. Companies frequently encounter a balancing act between expenses and sustainable practices, as eco-friendly approaches can often carry higher costs. However, fuzzy logic provides a systematic approach to weigh these conflicting goals, enabling decision-makers to prioritize sustainability without compromising cost-effectiveness.

Beyond supplier assessment, fuzzy logic has also been utilized in transportation planning to mitigate the environmental footprint of logistics operations. For example, Ganga and Carpinetti [9] showcased how fuzzy logic can be applied to refine transportation routes, leading to reduced fuel use and lower greenhouse gas emissions. These instances illustrate the adaptability of fuzzy logic in tackling the complex challenges posed by sustainability in SCM.

3 | Preliminaries

Fuzzy set theory and triangular fuzzy numbers present valuable mathematical frameworks for modeling uncertain systems, as outlined by Zadeh in 1965 [25]. Fundamentally, a fuzzy set serves as an enhancement of a traditional crisp set. Unlike crisp sets, which permit only complete membership or complete exclusion, fuzzy sets accommodate varying degrees of membership. This discussion draws heavily on the foundational concepts of fuzzy sets articulated by Chen in 2000 [26].

Within a defined universe of discourse, denoted as X, a fuzzy subset A of X is characterized by a membership function μ A (x). This function assigns each element x that belongs to X a real number within the range of [0, 1]. Consequently, the value derived from this function reflects the degree to which x belongs to A; higher values of μ A (x) signify a stronger association of x with A, as noted by Kaufmann and Gupta in 1991 [27].

It is important to note that a tilde preceding a variable signifies it as a fuzzy number throughout this text. A fuzzy number A can be expressed as $A=\{(x, \mu A(x) \mid x \in X\}$, representing a subset of the real numbers. This subset is defined through its membership function μ A (x), which continuously maps the real line $\Re$ to a closed interval [0, 1] and adheres to specific constraints notably, if the most certain region indicated by the membership function collapses to a singular point, denoted as b = d, a trapezoidal fuzzy number A transitions into a triangular fuzzy number (Refer to *Fig. 1*), typically represented by the triplet (a, b, c).

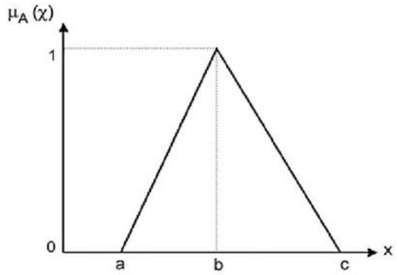

Fig. 1. Membership function of a triangular fuzzy number A= (a, b, c).

4 | Solution Approach

Our solution approach for the best logistics service provider selection comprises the following steps:

I. Identification of selection criteria using the transportation optimization framework.

II. Generating linguistic ratings for the criteria and the alternatives (service providers).

III. Best service provider selection using fuzzy.

A mathematical model including indices, sets, parameters, decision variables, an objective function, and constraints.

Sets

Raw material producers.	n
Pharmaceutical factory.	i
Distributor.	p
Pharmacies.	r
Products.	K
Refrigerated transportation vehicle.	v
Medicine.	m
Distribution center capacity.	l
Factory capacity.	l1

Parameters

If pharmaceutical company n can produce drug m, it is equal to one, otherwise, zero.	amn'
Amount of raw material m for producing product k.	hmk
Capacity of pharmaceutical company n for producing drug m.	bmn
Customer demand of customer r for product k under scenario s'.	Drks'
Capacity of factory i for product k with capacity level l.	Sikl
Capacity of distribution center p for product k with capacity level l'.	apktl'
Cost of purchasing each unit of drug m from pharmaceutical company n for factory i.	cnim''
Transportation cost of each unit of drug k from source ii to distribution center p via vehicle v.	cipkv
Production cost of each unit of product k in factory i.	gik
Capacity of vehicle v.	capv

Fixed cost contract with pharmaceutical company n.	fn
Setup cost of factory at location i with capacity p.	fli'
Setup cost of distribution center at location i with capacity p.	fl'p"
Probability of scenario s' occurring.	π s'

Objective function

$$\text{Minz} = \sum_{n} f_n e_n + \sum_{l}\sum_{i} f'_{li} e'_{li} + \sum_{l'}\sum_{p} f''_{l''p} e''_{l'p}$$
$$+\sum_{s'} \pi_{s'} \Bigg[\sum_{n}\sum_{i}\sum_{m} c''_{nim} Q_{nims'}$$
$$+\sum_{i}\sum_{p}\sum_{k}\sum_{v} c_{ipkv} X_{ipkvs'} + \sum_i \sum_k g_{ik} u_{iks'}$$
$$+\sum_{p}\sum_{r}\sum_{k}\sum_{v} c'_{pjkc} W_{pjkos'}\Bigg].$$

Constraints

s.t.

$$\sum_{i} Q_{nims'} \leq a'_{mn} b_{mn} e_n. \quad (1)$$

$$\sum_{n} Q_{nims'} = \sum_{k} h_{mk} u_{iks'}. \quad (2)$$

$$\sum_{i}\sum_{v} X_{ipkvs'} = \sum_{r}\sum_{o} W_{prkos}. \quad (3)$$

$$\sum_{p}\sum_{o} W_{prkos\ t} \geq D_{rks'}. \quad (4)$$

$$u_{iks'} \leq \sum_{i} S_{iktl} e'_{li}. \quad (5)$$

$$u_{iks'} = \sum_{p}\sum_{v} X_{ipkvs'}. \quad (6)$$

$$\sum_{i}\sum_{v} X_{ipkvs'} \leq \sum_{l,} a_{pktl'} e''_{l'p}. \quad (7)$$

$$\sum_{i}\sum_{p}\sum_{k} X_{ipkvs'} \leq cap_v. \quad (8)$$

$$\sum_{p}\sum_{r}\sum_{k} W_{prkos'} \leq cap'_o. \quad (9)$$

$$\sum_{l} e'_{li} \leq 1. \quad (10)$$

$$\sum_{l'} e''_{l'p} \leq 1. \quad (11)$$

$e_n e'_{li}, e''_{l',p} \in \{0,1\}$.

$Q_{nims}, X_{ipkvs}, W_{prkos'}, u_{iks\,I} \geq 0$.

Given the information is rather uncertain, a commission of decision-making experts was used to induce the conditions for selection criteria and the prospective mates using verbal variables. The verbal terms are latterly converted into numerical values (or fuzzy triangular figures) for further processing. The verbal term set consists of five terms with values ranging between veritably low (1, 1, 3) and veritably high (7, 9, 9). The fuzzy triangular figures are defuzzified. Given the fuzzy nature of the installation position selection problem, significance weights of individual attributes and conditions of druthers versus colorful private criteria are used as verbal variables in this study, and *Table 1* presents conditions of druthers versus colorful private criteria considered as verbal variables.

Table 1. Linguistic variables and fuzzy numbers for the ratings.

Fuzzy Number	Alternatives	Weight
(1,1,3)	Very Poor (VP)	Very Low (VL)
(1,3,5)	Poor (P)	Low (L)
(3,5,7)	Fair(F)	Medium(M)
(5,7,9)	Good (G)	High (H)
(7,9,9)	Very Good (VG)	Very High (VH)

A committee of three decision makers, D1, D2, and D3, with equal weight, is formed to rank and select the best alternative (logistics service provider). The three decision-makers utilize a five-point linguistic term set (See *Table 1*) to assess each alternative against the criteria presented in *Table 2*. Respective triangular fuzzy numbers represent the linguistic ratings.

Every MCDM problem involves the normalization stage. We use the modified vector normalization where the weight vector is defined in accordance. *Table 2* contains the fuzzy normalized weighted decision matrix.

Table 2. The weighted normalized decision matrix.

	A1	A2	A3	A4	Defuzzied //Valued	Normalize d//Weight
C1.1	(0.24,44.7,6.7)	(50.6,46.3,66.3)	(51.13,44.07,66.92)	(51.62,44.87,67.24)	49.93	0.1
Cl.2	(0.26, 52.7,75)	(58, 54.41,76)	57.58,53.73, 75.58)	58.6,55.76.63)	57.84	0.1
C1.3	(0.23,41.25,63.75)	(45.68, 39.64,62.38)	(44.31,37.93, 60.90)	(42.87,36,12,59.32)	44.53	0.09
C1.4	(0.2,39.1,62.3)	(44.1,37.3,60.8)	(44.07,37.57,60.66)	(42.58,35.74,59.06)	43.64	0.09
C1.5	(0.24, 45.69,70.5)	(53.1.46.64,71.12)	(53.8, 47.6 9,71.8)	(54.53,48.83,72.53)	53.04	0.11
C1.6	(0.2,50.3,73.5)	(56.3,51.76,74.37)	(55.82,50.87,73.82)	(55.22,49.92,73.22)	55.45	0.12
C2.1	(4.72,2.26,8)	(4.72,2.26,7.5)	(4.68,2.38,7.95)	(4.83, 2.5,8.4)	4.646	0.01
C2.2	(0.12,4.2,13.9)	(7.45,4.34,13.5)	(7.647, 4.45,13.47)	(7.85, 4.56,13.34)	7.899	0.01
C2.3	(0.11,3.5, 12.44)	(6.35,3.59,12.24)	(6.4,3.62,12.02)	(6.56,3.9,13)	6.99	0.01
C3.1	(0.31,22.36,45.69)	(30.57,23.03 ,46.64)	(30.120,22.14,45.39)	(30.29,22.8,46.32)	30.47	0.06
C3.2	(34.82,26.7,51.76)	(34.82,26.7,51.76)	(36.10, 27.82,53.3)	(36.12,27.26,52.53)	35.23	0.07
C3.3	(0.34,25.69,50.36)	(34.82, 26.70,51.76)	(36.1, 27.82,53.3)	(36.12,27.26,52.53)	35.23	0.07

The resulting fuzzy number is subsequently converted into a precise value. The evaluation indicates that company A4 stands out as the most promising logistics partner, while company A1 is viewed as the least favorable option. In summary, this research presents a detailed transportation model specifically designed for the pharmaceutical industry. By incorporating fuzzy logic, the model effectively addresses the uncertainties and variations inherent in pharmaceutical logistics, thereby facilitating sound decision-making. The analysis highlights the necessity of optimizing transportation procedures to boost efficiency and minimize expenses within pharmaceutical supply chains. Future investigations could explore additional variables and techniques to enhance further the model's efficiency and relevance in practical pharmaceutical logistics scenarios. Overall, this study enhances the understanding and management of pharmaceutical transportation systems, providing valuable insights for both practitioners and researchers in this domain.

5 | Conclusion

The pharmaceutical supply chain plays a crucial role in global healthcare systems, yet it faces numerous challenges that compromise its effectiveness and reliability. These issues—stemming from pandemics, political tensions, and counterfeit medications—highlight the urgent need for innovative strategies to bolster the resilience of the supply chain. Fuzzy logic has emerged as a robust tool for tackling these problems, offering a systematic approach to decision-making in uncertain situations. By accommodating vague and subjective information, fuzzy logic allows decision-makers to assess multiple factors at once, including cost, quality, and delivery timelines, which helps in optimizing supply chain operations [7].

The use of fuzzy logic within pharmaceutical supply chains has yielded substantial advantages, particularly in supplier assessment, inventory control, and logistical planning. For example, fuzzy multi-criteria decision-making models have been developed to evaluate suppliers based on various criteria, thereby streamlining the selection process and enhancing overall supply chain efficiency [21]. Additionally, fuzzy logic methods in inventory management have shown efficacy in reducing expenses while ensuring the availability of essential medical supplies [22]. Beyond addressing operational hurdles, fuzzy logic has also indicated potential in incorporating sustainability considerations into supply chain decision-making processes. By assessing suppliers and transportation options through the lens of environmental and social factors, businesses can align their practices with global sustainability objectives while maintaining cost-effectiveness [28]. These applications demonstrate the flexibility of fuzzy logic in confronting the diverse challenges faced by pharmaceutical supply chains.

However, the adoption of fuzzy logic in these supply chains is not without its drawbacks. The dependence on subjective information and expert insights can lead to biases, and the intricate nature of fuzzy models may create difficulties for those not well-versed in the methodology. To overcome these challenges, additional research and the creation of accessible tools and frameworks are essential to promote the integration of fuzzy logic into SCM [6].

Looking forward, merging fuzzy logic with cutting-edge technologies like AI and blockchain presents thrilling prospects for boosting resilience and transparency in supply chains. AI-powered predictive analytics can enhance demand forecasting and optimize inventory management, while blockchain guarantees traceability and the reliability of supply chain processes [6]. These innovations hold the promise of revolutionizing pharmaceutical supply chains, making them more flexible and sturdier in the face of increasing uncertainties. In summary, fuzzy logic offers a valuable method for refining pharmaceutical supply chains, tackling both operational and sustainability issues. By utilizing this approach, companies can enhance efficiency, reduce expenses, and make more informed decisions, ultimately facilitating the distribution of essential medications to patients worldwide. Future studies should focus on integrating fuzzy logic with emerging technologies and exploring its applications in various aspects of SCM, thereby setting the stage for more robust and adaptable supply chain strategies.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

All data are included in the text.

Funding

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

References

[1] Panigrahi, S., Yadav, A., & Singh, S. P. (2019). A fuzzy multi-criteria decision-making framework for sustainable supplier evaluation and selection. *Journal of cleaner production*, *228*. https://doi.org/10.1111/jscm.12258

[2] LeBaron, G. (2021). The role of supply chains in the global business of forced labour. *Journal of supply chain management*, *57*(2), 29–42. https://doi.org/10.1111/jscm.12258

[3] Susarla, S., & Karimi, I. A. (2012). A multiperiod mixed-integer programming model for pharmaceutical supply chain planning. *Industrial & engineering chemistry research*, *51*(42), 13749–13761. https://doi.org/10.1021/ie3012113

[4] Privett, N. (2014). Improving global health supply chains. *Yale global health review*, *1*(1), 30–33. https://www.cgdev.org/sites/default/files/improving-global-health-supply-chains-through-traceability.pdf

[5] Gunasekaran, A., Papadopoulos, T., Dubey, R., Wamba, S. F., Childe, S. J., Hazen, B., & Akter, S. (2024). Supply chain flexibility and post-pandemic resilience. *Global journal of flexible systems management*, *24*(1), 00375. https://doi.org/10.1007/s40171-024-00375-2

[6] Roy, A., Mohapatra, A., Sharwan, C., Kumar, A., Kumar, S., Maholay, A., & Conneh, C. C. (2025). Artificial intelligence in pharmaceutical supply chain management: A systemic review. *World journal of biology pharmacy and health sciences*, *21*(1), 204–213. https://journalwjbphs.com/node/292

[7] Zimmermann, H. (1985). Decision making in fuzzy environments. In *Dordrecht: Springer* (pp. 213–260). https://doi.org/10.1007/978-94-015-7153-1_12

[8] Barcellos de Paula, L. (2021). Sustainable management of the supply chain based on fuzzy logic. *Cybernetics and systems*, *52*(7), 579–600. https://doi.org/10.1080/01969722.2021.1910763

[9] Ganga, G. M. D., & Carpinetti, L. C. R. (2011). A fuzzy logic approach to supply chain performance management. *International journal of production economics*, *134*(1), 177–187. https://doi.org/10.1016/j.ijpe.2011.06.011

[10] Uthayakumar, R., & Priyan, S. (2013). Pharmaceutical supply chain and inventory management strategies: Optimization for a pharmaceutical company and a hospital. *Operations research for health care*, *2*(3), 52–64. https://doi.org/10.1016/j.orhc.2013.08.001

[11] Amaro, A. C. S., & Barbosa-Póvoa, A. P. F. D. (2008). Planning and scheduling of industrial supply chains with reverse flows: A real pharmaceutical case study. *Computers & chemical engineering*, *32*(11), 2606–2625. https://doi.org/10.1016/j.compchemeng.2008.03.006

[12] Liu, S., & Papageorgiou, L. G. (2013). Multiobjective optimisation of production, distribution and capacity planning of global supply chains in the process industry. *Omega*, *41*(2), 369-382. https://doi.org/10.1016/j.omega.2012.03.007. *Omega*, *41*(2), 369–382.

[13] Jalal, A., Khodadadi, M., Tavakkoli-Moghaddam, R., & Khalilzadeh, M. (2022). A robust optimization model for multi-product multi-period supply chain distribution considering various transportation modes under uncertainty. *Applied soft computing*, *125*, 109046. https://doi.org/10.1016/j.asoc.2022.109046

[14] Koh, S. C. L., & Tan, K. H. (2006). Translating knowledge of supply-chain uncertainty into business strategy and action. *Journal of manufacturing technology management*, *17*(4), 472–485. https://doi.org/10.1108/17410380610661707

[15] Chiu, M., & Lin, G. (2004). Collaborative supply chain planning using the artificial neural network approach. *Journal of manufacturing technology management*, *15*(8), 787–796. https://doi.org/10.1108/17410380410565375

[16] Sousa, R. T., Shah, N., & Papageorgiou, L. G. (2011). Global supply chain planning for pharmaceuticals. *Chemical engineering research and design*, *89*(11), 2396–2409. https://doi.org/10.1016/j.cherd.2011.04.003

[17] Susarla, N., & Karimi, I. A. (2012). Integrated supply chain planning for multinational pharmaceutical enterprises. *Computers & chemical engineering*, *42*, 168–177. https://doi.org/10.1016/j.cherd.2011.04.003

[18] Liu, S., & Papageorgiou, L. G. (2013). Multiobjective optimisation of production, distribution and capacity planning of global supply chains in the process industry. *Omega*, *41*(2), 369–382. https://doi.org/10.1016/j.omega.2012.03.007

[19] Mackey, T. K., & Liang, B. A. (2011). The global counterfeit drug trade: patient safety and public health risks. *Journal of pharmaceutical sciences*, *100*(11), 4571–4579. https://doi.org/10.1002/jps.22679

[20] Yazıcılar Sola, F. G., & Güzel, D. (2025). The role of supply chain transparency and supplier trust in the impact of blockchain technology adoption on new product development. *Sustainability*, 17(11). https://doi.org/10.3390/su17115171

[21] De Sá Ferreira F. (2019). The impact of fuzzy logic on logistics optimization: A comprehensive review. *RevistaFT*, *23*(70). https://doi.org/10.69849/revistaft/ar10201901011035

[22] Priyan, S., & Uthayakumar, R. (2014). Optimal inventory management strategies for pharmaceutical company and hospital supply chain in a fuzzy–stochastic environment. *Operations research for health care*, *3*(4), 177–190. https://doi.org/10.1016/j.orhc.2014.08.001

[23] Bijvank, M., & Vis, I. F. (2012). Inventory control for point-of-use locations in hospitals. *Journal of the operational research society*, *63*(4), 497–510. https://doi.org/10.1057/jors.2011.52

[24] Anilkumar, E. N, & Sridharan, R. (2019). Sustainable supply chain management: A literature review and implications for future research. *International journal of system dynamics applications*, *8*, 15–52. https://doi.org/10.4018/IJSDA.2019070102

[25] Zadeh, L. A. (1965). Fuzzy sets. *Information and control*, *8*(3), 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

[26] Chen, C. T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy sets and systems*, *114*(1), 1–9. 10.1016/S0165-0114(97)00377-1

[27] Kaufmann, A., & Gupta, M. M. (1991). *Introduction to fuzzy arithmetic: Theory and applications*. Van Nostrand Reinhold. https://books.google.com/books?id=UjuMAAAAMAAJ

[28] Roy, S. A., Ali, S. M., Kabir, G., Enayet, R., Suhi, S. A., Haque, T., & Hasan, R. (2019). A framework for sustainable supplier selection with transportation criteria. *International journal of sustainable engineering*, *13*(2), 77–92. https://doi.org/10.1080/19397038.2019.1625983