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Pharmaceutical Fuzzy Optimization

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Abstract

In response to the urgent demands of pharmaceutical-supply-chains (PSC), there has been a rapid emergence of optimization processes as effective tools for enhancing the working of these chain-networks. This study introduces an innovative approach called the location-allocation-inventory model, which addresses the complexities of a multi-modal transportation-system within the PSCN, considering uncertainties. The primary goal of this model is to optimize various objectives, including minimizing overall-costs and delivery-time while maximizing the reliability of the transportation-system. To mitigate the effects of uncertain-parameters such as ordering of products, delivery of the products, purchase, and transportation-costs, as well as the vehicle capacity, warehouses, and distribution-centres, a robust-fuzzy-optimization approach is employed. The study also presents a modified version of the state-of-the-art evolutionary-algorithm known as the RDA(Red-Deer-Algorithm), referred to as the IMORDA(Improved-Multi-Objective-Red-Deer-Algorithm), and compares its performance with other well-established algorithms such as the Non-dominated-Sorting-Genetic-Algorithm and the MOPSO(Multi-Objective-Particle-Swarm-Optimization). The findings of the study validate the effectiveness and suitability of the IMORDA for the proposed-model, thereby encouraging further advancements in this promising meta-heuristic approach.

Keywords: PSC, reliability, delivery-time, robust-fuzzy-approach-evolutionary-algorithms, RDA.

Article type: Research article

1 Introduction

The economic and social significance of the pharmaceutical industry has led governments to prioritize the working-design and management of pharmaceutical-supply-chain networks, ensuring the availability and timely distribution of medications to end-users. The complexity and global reach of the industry, coupled with its critical role in public health, necessitate the use of optimization techniques to streamline logistic activities within the supply chain. As the number of medication markets expands worldwide, the importance of optimization models and algorithms in this research field grows, particularly in underdeveloped countries where pharmaceutical-supply-chain management is a pressing concern.

To address these challenges, this research-paper proposes a novel-location-allocation-inventory-model for the design of multi-modal transportation-system within the pharmaceutical-supply-chain network. Emphasis is placed on managing uncertainties and considering factors such as delivery time and reliability, especially in regions with limited resources. The study acknowledges that medication distribution extends beyond health centres to individual users, and therefore, reliability within the supply chain becomes crucial. Multi-modal transportation is highlighted as a key strategy for improving various aspects, including distribution time, service quality, facility utilization, and energy reduction. Given that logistic costs account for over 40% of medication prices, optimizing these costs is a primary objective. To address the uncertainties inherent in the model's parameters and variables, a robust-fuzzy optimization approach is employed, as it provides a suitable framework for controlling uncertainty. However, due to the complexity of the current pharmaceutical-supply-chain network on a vast scale, the model becomes NP-Hard, and traditional algorithms exhibit poor performance in handling such complexity. Furthermore, incorporating reliability and delivery time as additional factors exacerbates the problem's complexity. To overcome these challenges, an efficient modification of the Red-Deer-Algorithm (RDA), a recently developed meta-heuristic, is proposed as a solution.

The key-contributions of this research are:

i. Introducing a multi-objective, multi-product, multi-echelon pharmaceutical-supply-chain network with multi-modal-transportation.

ii. Considering 3 main-objectives: total-cost, delivery-time, and transportation system reliability for medication.

iii. Developing a robust-fuzzy approach to address parameter-uncertainty.

iv. Presenting an efficient modification of the multi-objective RDA for solving the proposed model.

Previous studies in this area have tackled aspects of pharmaceutical-supply-chain design, with varying approaches. Sousa.et.al (2005) developed a facility location-allocation-model using a heuristic approach on Lagrangian-decomposition. Susarla-Karimi [1] utilized a MILP approach to create an integrated multi-echelon, multi-period pharmaceutical-supply-chain. Mousazadeh.et.al [2] proposed a robust-possibilistic-programming approach for a bi-objective pharmaceutical-supply-chain-network design problem. Harsen and Grunow [3] addressed the optimal assignment of pharmacies in a two-stage stochastic-model, considering distribution and medication pricing risks. Zahiri et al. [4] introduced a multi-objective, multi-echelon pharmaceutical-supply-chain network design with resilience, utilizing fuzzy-possibilistic-stochastic-programming and differential evolutionary and genetic algorithms. Sridevi et al.[5] used LGP and goal programming in rice farm. Shalini et al [6] implemented goal programming in rice farm for nutrient management. Vaidya et al [7] wrote an overview paper for AHP applications. Terzi et al [8] developed AHP for complex decision problem. Subramanian et.al [9] review applications for Analytic Hierarchy Process in operations management. Ammarapala et al [10] developed AHP for Cross-border shipment route selection. Cross-border shipment route selection utilizing analytic hierarchy process (AHP) method
In summary, this research addresses the pressing need for effective pharmaceutical-supply-chain-network design and management. The given model, coupled with the developed robust-fuzzy optimization approach and the modified multi-objective RDA, offers valuable contributions to this field, paving the way for improved efficiency and reliability in the delivery of medications.

2 Mathematical Formulation:

The pharmaceutical-supply-chain-network-design problem involves four levels, including domestic-manufacturing and foreign-manufacturing centres, warehouses, distribution centres, and customer zones consisting of pharmacies in the communities as well as hospitals. The production centres play a crucial part in the delivery of pharmaceutical-products. The transportation costs in this network are variable and the transportation system operates through multiple modes, allowing for flexibility in travel routes. To optimize DCs, batch delivery is considered, where multiple products are transported together. Additionally, the distribution centres account for both the preparation and packaging-costs of the products.
Key assumptions made in this model include: - Designing a multi-level, multi-product, and multi-period PSCN that incorporates domestic-manufacturing and foreign-manufacturing centres, warehouses, distribution centres, and customers (pharmacies as well as hospitals).
Every vehicle has a maximum travelling distance per period. Customers have the capacity to receive multiple vehicles of pharmaceutical products at any given time. Transportation-costs for pharmaceutical-products vary depending on the vehicles used and the specific routes taken.
The reliability of the multi-modal-transportation-system and specific routes are subject to variations.To tackle the challenges posed by these assumptions and the complexity of the pharmaceutical-supply-chain-network design problem, a robust-fuzzy optimization method has been developed. This method enables the model to address uncertainties associated with various parameters and variables, providing a robust and reliable solution. By incorporating fuzzy logic, the approach can handle the vagueness and imprecision of real-world uncertainties effectively.
In summary, the proposed-robust-fuzzy optimization method is designed to address the intricate nature of the pharmaceutical-supply-chain network design problem. It allows for the consideration of multiple levels, products, and time periods, taking into account the variability of transportation costs and the reliability of the multi-modal-transportation system. By employing this method, the model can provide robust and efficient solutions to optimize the network design and improve the overall performance of the pharmaceutical-supply-chain.

Fmax=

$$\{\sum_w \sum_{p'} \sum_t Ihc^t_{wp'}\, IQ^t_{p'w} + \sum_m \sum_{p'} \sum_t Ihc^t_{mp'}\, IQ^t_{p'm} + \sum_{m'} \sum_{p'} \sum_t Ihc^t_{m'p'}\, IQ^t_{p'm'} + \sum_d \sum_{p'} \sum_t Ihc^t_{dp'}\, IQ^t_{p'd}\,\}$$

+D{ $\sum_w \sum_m \sum_{p'} \sum_t K^t_{p'wm}$ +$\sum_w \sum_{m'} \sum_{p'} \sum_t K^t_{p'wm'}$ +$\sum_d \sum_m \sum_{p'} \sum_t K^t_{p'dm}$ +$\sum_d \sum_{m'} \sum_{p'} \sum_t K^t_{p'dm'}$ + $\sum_d \sum_w \sum_{p'} \sum_t K^t_{p'dw}$ +$\sum_{c_p} \sum_w \sum_{p'} \sum_t K^t_{p'c_pw}$ +$\sum_{c_{hp}} \sum_w \sum_{p'} \sum_t K^t_{p'c_{hp}w}$ +$\sum_{c_p} \sum_d \sum_{p'} \sum_t K^t_{p'c_pd}$ + $\sum_{c_{hp}} \sum_d \sum_{p'} \sum_t K^t_{p'c_{hp}d}$ }

+{ $\sum_{p'} \sum_t Pcw^t_{p'} \left(\sum_{c_p} W^t_{p'c_p} + \sum_{c_{hp}} W^t_{p'c_{hp}} \right) + \sum_{p'} \sum_t Pcl^t_{p'} \left(\sum_{c_p} U^t_{p'c_p} + \sum_{c_{hp}} U^t_{p'c_{hp}} \right)$} + { $\sum_A \sum_{p'} \sum_t Ltc^t_{p'A}$ X $\sum_A \sum_{p'} \sum_{v_A} U^A_{p'v_A}$ } + { $\sum_m \sum_{p'} \sum_t \left(Pc^t_{p'm} X\ PQ^t_{p'm} \right)$ +

{$\sum_m \sum_{p'} \sum_t (Pc^t_{p'm}\ X\ PQ^t_{p'm})$ } + { $\sum_m \sum_w d_{mw}$ ($\sum_w \sum_m \sum_{p'} \sum_v \sum_{r_{mw}} \left(Tc^{o\,r_{mw}}_{p'mwv} X\, SQ^{tr_{mw}}_{p'mwv} \right)$ + ($\sum_w \sum_m \sum_{p'} \sum_{v_A} \sum_{r_{m'w}} \left(Tc^{o\,r_{mw}}_{p'mwv_A}\ SQ^{tr_{mw}}_{p'mwv_A} \right)$+

$\sum_m \sum_w d_{m'w}$ ($\sum_w \sum_m \sum_{p'} \sum_v \sum_{r_{m'w}} \left(Tc^{o\,r_{mw}}_{p'mwv}\ SQ^{tr_{mw}}_{p'mwv} \right) \sum_{m'} \sum_w dm'w (\sum_{p'} \sum_{m'} \sum_w \sum_{v_A} \sum_{r_{m'w}} Tc^{o\,r_{m'w}}_{p'm'wv_A}$ $\sum_t SQ^{tr_{mw}}_{p'mwv_A}$)

+$\sum_m \sum_d d_{md} (\sum_{p'} \sum_m \sum_{d'} \sum_V \sum_{r_{md}} Tc^{o\,r_{md}}_{p'mdv} \sum_t SQ^{tr_{md}}_{p'mdv})$+ $\sum_{p'} \sum_m \sum_{d'} \sum_{v_A} \sum_{r_{md}} Tc^{o\,r_{md}}_{p'mdv_A}) \sum_t SQ^{tr_{md}}_{p'mdv_A}$)+ $\sum_{m'} \sum_d d_{m'd} (\sum_{p'} \sum_{m'} \sum_d \sum_{v_A} \sum_{r_{m'd}} Tc^{o\,r_{m'd}}_{p'm'dv_A} \sum_t SQ^{tr_{m'd}}_{p'm'dv_A}$)+$\sum_w \sum_d d_{wd}$ ($\sum_{p'} \sum_w \sum_d \sum_v \sum_{r_{wd}}$ ($Tc^{or_{wd}}_{p'wdv}$ $\sum_t SQ^{tr_{wd}}_{p'wdv}$)+$\sum_{p'} \sum_m \sum_d \sum_{v_A} \sum_{r_{md}} (Tc^{or_{wd}}_{p'wdv_A}\ \ \sum_t SQ^{tr_{wd}}_{p'wdv_A}$))+ $\sum_w \sum_{cp} d_{wco} (\sum_{p'} \sum_w \sum_{cp} \sum_v \sum_{r_{wcp}}$ ($Tc^{or_{wcp}}_{p'wcpv}$ $\sum_t SQ^{tr_{cpd}}_{p'wcpv}$)

+$\sum_{p'} \sum_w \sum_{cp} \sum_{v_A} \sum_{r_{wcp}} \left(Tc^{or_{wcp}}_{p'wcpv_A}\ \ \sum_t SQ^{tr_{cpd}}_{p'wcpv_A} \right)$)+ $\sum_w \sum_d d_{wd} (\sum_{p'} \sum_w \sum_d \sum_v \sum_{r_{wd}} \left(Tc^{or_{wd}}_{p'wdv} \sum_t SQ^{tr_{wd}}_{p'wdv} \right)$

+$\sum_{p'} \sum_m \sum_d \sum_{v_A} \sum_{r_{md}} (Tc^{or_{wd}}_{p'wdv_A}\ \ \sum_t SQ^{tr_{wd}}_{p'wdv_A}$))+$\sum_w \sum_{chp} d_{wchp} (\sum_{p'} \sum_w \sum_{chp} \sum_V \sum_{r_{wchp}} (Tc^{or_{wchp}}_{p'wchpv}$ $\sum_t SQ^{tr_{wchp}}_{p'wchpv}$))+ $\sum_{p'} \sum_w \sum_{chp} \sum_{v_A} \sum_{r_{wchp}} (Tc^{or_{wchp}}_{p'wchpv_A}\ \ \sum_t SQ^{tr_{wchp}}_{p'wchpv_A}$)+$\sum_d \sum_w d_{wcp} (\sum_{p'} \sum_d \sum_{cp} \sum_V \sum_{r_{dcp}}$ ($Tc^{or_{dcp}}_{p'dcpv}\ \ \sum_t SQ^{tr_{dcp}}_{p'dcpv}$))+ ($\sum_{p'} \sum_d \sum_{cp} \sum_{v_A} \sum_{r_{dcp}} (Tc^{or_{dcp}}_{p'dcpv_A}$ $\sum_t SQ^{tr_{dcp}}_{p'dcpv_A}$)+$\sum_d \sum_{chp} d_{dchp} (\sum_{p'} \sum_d \sum_{chp} \sum_V \sum_{r_{dchp}} (Tc^{or_{dchp}}_{p'dchpv}\ \ \sum_t SQ^{tr_{dcp}}_{p'dchpv}$))+ ($\sum_{p'} \sum_d \sum_{chp} \sum_{v_A} \sum_{r_{dchp}}$ ($Tc^{or_{dchp}}_{p'dchpv_A}\ \ \sum_t SQ^{tr_{dchp}}_{p'dchpv_A}$)}+{$\sum_{p'} \sum_m \sum_t (Boc^t_{p'm}\ \ BOQ^t_{p'm}) + \sum_{p'} \sum_{m'} \sum_t (Boc^t_{p'm'}\ \ BOQ^t_{p'm'})$} + {$\sum_d \sum_t$ (F_d Ec^t_d)}+$\sum_{p'} \sum_w \sum_t$ ($F_d\ \ Kc^t_{p'w}$)}+{$\sum_m F_{cm}\ \ F_m + \sum_{m'} Fc_{m'}\ \ F_m \sum_w Fc_w\ \ F_w$} +{$\sum_{p'} \sum_w \sum_m \sum_t$ ($Ppc^{ot}_{p'wm'}$ $PN^t_{p'wm}$)+ $\sum_{p'} \sum_w \sum_{m'} \sum_t$ ($Ppc^{ot}_{p'wm'}\ \ PN^t_{p'wm'}$)+$\sum_{p'} \sum_d \sum_m \sum_t$ ($Ppc^{ot}_{p'dm}\ \ PN^t_{p'dm}$)+$\sum_{p'} \sum_d \sum_{m'} \sum_t$ ($Ppc^{ot}_{p'dm'}$ $PN^t_{p'dm'}$)+$\sum_{p'} \sum_{cp} \sum_w \sum_t$ ($Ppc^{ot}_{p'cpw}\ \ PN^t_{p'cpw}$)+$\sum_{p'} \sum_{chp} \sum_w \sum_t$ ($Ppc^{ot}_{p'chpw}\ \ PN^t_{p'chpw}$)+$\sum_{p'} \sum_{cp} \sum_d \sum_t$ ($Ppc^{ot}_{p'cpd}$

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$$PN^{t}_{p'cpd})+\sum_{p'}\sum_{chp}\sum_{d}\sum_{t}(Ppc^{ot}_{p'chpd}\ \ PN^{t}_{p'chpd})\}+\sum_{w}\sum_{m}\sum_{p'}\sum_{r_{mw}}\sum_{t} Dc^{t}_{wmp'}$$

$$Q^{tr_{mw}}_{p'mw}\sum_{w}\sum_{m'}\sum_{p'}\sum_{r_{m'w}}\sum_{t} Dc^{t}_{wm'p'}\ \ Q^{tr_{m'w}}_{p'm'w}+\sum_{d}\sum_{m}\sum_{p'}\sum_{r_{md}}\sum_{t} Dc^{t}_{dmp'}\ \ Q^{tr_{md}}_{p'md}+\sum_{d}\sum_{m'}\sum_{p'}\sum_{r_{m'd}}\sum_{t} Dc^{t}_{dm'p'}$$

$$Q^{tr_{m'd}}_{p'm'd}+\sum_{d}\sum_{w}\sum_{p'}\sum_{r_{wd}}\sum_{t} Dc^{t}_{dwp'}\ \ Q^{tr_{wd}}_{p'wd}+\sum_{cp}\sum_{w}\sum_{p'}\sum_{r_{wcp}}\sum_{t} Dc^{t}_{cpwp'}$$

$$Q^{tr_{wcp}}_{p'wcp}+\sum_{chp}\sum_{w}\sum_{p'}\sum_{r_{wchp}}\sum_{t} Dc^{t}_{chpwp'}\ \ Q^{tr_{wchp}}_{p'wchp}+\sum_{cp}\sum_{d}\sum_{p'}\sum_{r_{dcp}}\sum_{t} Dc^{t}_{cpdp'}$$

$$Q^{tr_{dcp}}_{p'dcp}+\sum_{chp}\sum_{d}\sum_{p'}\sum_{r_{dchp}}\sum_{t} Dc^{t}_{chpdp'}\ \ Q^{tr_{dchp}}_{p'dchp}$$

Fmin=

$$\{\ \sum_{w}\sum_{p'}\sum_{t} Ihc^{t}_{wp'}\ \mathrm{X}\ IQ^{t}_{p'w}+\sum_{m}\sum_{p'}\sum_{t} Ihc^{t}_{mp'}\times IQ^{t}_{p'm}+\sum_{m'}\sum_{p'}\sum_{t} Ihc^{t}_{m'p'}\ \mathrm{X}\ IQ^{t}_{p'm'}$$

$$+\sum_{d}\sum_{p'}\sum_{t} Ihc^{t}_{dp'}\,\mathrm{X}\,IQ^{t}_{p'd}\ \}$$

$$+\mathrm{D}\{\sum_{w}\sum_{m}\sum_{p'}\sum_{t} K^{t}_{p'wm}+\sum_{w}\sum_{m'}\sum_{p'}\sum_{t} K^{t}_{p'wm'}+\sum_{d}\sum_{m}\sum_{p'}\sum_{t} K^{t}_{p'dm}+\sum_{d}\sum_{m'}\sum_{p'}\sum_{t} K^{t}_{p'dm'}+$$

$$\sum_{d}\sum_{w}\sum_{p'}\sum_{t} K^{t}_{p'dw}+\sum_{c_p}\sum_{w}\sum_{p'}\sum_{t} K^{t}_{p'c_pw}+\sum_{c_{hp}}\sum_{w}\sum_{p'}\sum_{t} K^{t}_{p'c_{hp}w}+\sum_{c_p}\sum_{d}\sum_{p'}\sum_{t} K^{t}_{p'c_pd}+$$

$$\sum_{c_{hp}}\sum_{\mathrm{d}}\sum_{p'}\sum_{t} K^{t}_{p'c_{hp}d}\}\ +\ \{\sum_{p'}\sum_{t} Pcw^{t}_{p'}\left(\sum_{c_p} W^{t}_{p'c_p}+\sum_{c_{hp}} W^{t}_{p'c_{hp}}\right)+$$

$$\sum_{p'}\sum_{t} Pcl^{t}_{p'}\left(\sum_{c_p} U^{t}_{p'c_p}+\sum_{c_{hp}} U^{t}_{p'c_{hp}}\right)\}\ +\ \{\ \sum_{A}\sum_{p'}\sum_{t} Ltc^{t}_{p'A}\ \ \mathrm{X}\sum_{\mathrm{A}}\sum_{p'}\sum_{v_A} U^{A}_{p'v_A}\}\ +\ \{$$

$$\sum_{m}\sum_{p'}\sum_{t}(Pc^{t}_{p'm}X\ PQ^{t}_{p'm})+$$

$$\sum_{m'}\sum_{p'}\sum_{t}(Pc^{t}_{p'm'}\ X\ PQ^{t}_{p'm'})\ \}\ +\ \{\ \sum_{\mathrm{m}}\sum_{w} d_{mw}\ (\sum_{\mathrm{w}}\sum_{m}\sum_{p'}\sum_{v}\sum_{r_{mw}}\left(Tc^{t\,r_{mw}}_{p'mwv}X\,SQ^{tr_{mw}}_{p'mwv}\right.$$

$$\left.\right)+(\sum_{\mathrm{w}}\sum_{m}\sum_{p'}\sum_{v_A}\sum_{r_{mw}}\left(Tc^{t\,r_{mw}}_{p'mwv_A}X\ SQ^{tr_{mw}}_{p'mwv_A}\right)+\sum_{\mathrm{m'}}\sum_{w} d_{m'w}\ (\sum_{\mathrm{w}}\sum_{m'}\sum_{p'}\sum_{v_A}\sum_{r_{m'w}}\left(\right.$$

$$Tc^{t\,r_{m'w}}_{p'm'wv_A}X\,SQ^{tr_{m'w}}_{p'm'wv_A}$$

$$\left.\right)+\sum_{m'}\sum_{w} dm'w(\sum_{p'}\sum_{m'}\sum_{w}\sum_{v_A}\sum_{r_{m'w}} Tc^{t\,r_{m'w}}_{p'm'wv_A}\sum_{t} SQ^{tr_{mw}}_{p'mwv_A})+\sum_{m}\sum_{d} d_{md}($$

$$\sum_{p'}\sum_{m}\sum_{d'}\sum_{v}\sum_{r_{md}} Tc^{t\,r_{md}}_{p'mdv}X\sum_{t} SQ^{tr_{md}}_{p'mdv})+\sum_{p'}\sum_{m}\sum_{d'}\sum_{v_A}\sum_{r_{md}} Tc^{t\,r_{md}}_{p'mdv_A})\mathrm{X}\sum_{t} SQ^{tr_{md}}_{p'mdv_A})+\sum_{m'}\sum_{d} d_{m'd}($$

$$\sum_{p'}\sum_{m'}\sum_{d}\sum_{v_A}\sum_{r_{m'd}} Tc^{t\,r_{m'd}}_{p'm'dv_A}\ \mathrm{X}\ \sum_{t} SQ^{tr_{m'd}}_{p'm'dv_A})+\sum_{w}\sum_{d} d_{wd}\ \ (\sum_{p'}\sum_{w}\sum_{d}\sum_{v}\sum_{r_{wd}}(\ Tc^{pr_{wd}}_{p'wdv}\times\sum_{t} SQ^{tr_{wd}}_{p'wdv})$$

$$+\sum_{p'}\sum_{m}\sum_{d}\sum_{v_A}\sum_{r_{md}}(Tc^{pr_{wd}}_{p'wdv_A}\ \times\sum_{t} SQ^{tr_{wd}}_{p'wdv_A}))+\ \ \sum_{w}\sum_{cp} d_{wco}\ \ \ (\sum_{p'}\sum_{w}\sum_{cp}\sum_{v}\sum_{r_{wcp}}(\ Tc^{r_{wcp}}_{p'wcpv}\times$$

$$\sum_{t} SQ^{tr_{cpd}}_{p'wcpv})\ \ +\sum_{p'}\sum_{w}\sum_{cp}\sum_{v_A}\sum_{r_{wcp}}(Tc^{pr_{wcp}}_{p'wcpv_A}\ \times\sum_{t} SQ^{tr_{cpd}}_{p'wcpv_A}))+\ \sum_{w}\sum_{d} d_{wd}\ \ (\sum_{p'}\sum_{w}\sum_{d}\sum_{v}\sum_{r_{wd}}($$

$$Tc_{p'wdv}^{pr_{wd}} \times \sum_t SQ_{p'wdv}^{tr_{wd}})+\sum_{p'}\sum_m \sum_d \sum_{v_A} \sum_{r_{md}} (Tc_{p'wdv_A}^{pr_{wd}}$$

$$\sum_t SQ_{p'wdv_A}^{tr_{wd}}))+\sum_w \sum_{chp} d_{wchp} (\sum_{p'}\sum_w \sum_{chp} \sum_v \sum_{r_{wchp}} (Tc_{p'wchpv}^{pr_{wchp}}$$

$$\sum_t SQ_{p'wchpv}^{tr_{wchp}}))+ \sum_{p'}\sum_w \sum_{chp} \sum_{v_A} \sum_{r_{wchp}} (Tc_{p'wchpv_A}^{pr_{wchp}} \times$$

$$\sum_t SQ_{p'wchpv_A}^{tr_{wchp}})+\sum_d \sum_w d_{wcp} (\sum_{p'}\sum_d \sum_{cp} \sum_v \sum_{r_{dcp}} (Tc_{p'dcpv}^{pr_{dcp}} \quad \sum_t SQ_{p'dcpv}^{tr_{dcp}}))+ (\sum_{p'}\sum_d \sum_{cp} \sum_{v_A} \sum_{r_{dcp}} ($$

$$Tc_{p'dcpv_A}^{pr_{dcp}} \quad \sum_t SQ_{p'dcpv_A}^{tr_{dcp}})+\sum_d \sum_{chp} d_{dchp}(\sum_{p'}\sum_d \sum_{chp} \sum_v \sum_{r_{dchp}} (Tc_{p'dchpv}^{pr_{dchp}}$$

$$\sum_t SQ_{p'dchpv}^{tr_{dcp}}))+ (\sum_{p'}\sum_d \sum_{chp} \sum_{v_A} \sum_{r_{dchp}} (Tc_{p'dchpv_A}^{pr_{dchp}} \quad \sum_t SQ_{p'dchpv_A}^{tr_{dchp}})\}+\{\sum_{p'}\sum_m \sum_t(Boc_{p'm}^t \quad BOQ_{p'm}^t) +$$

$$\sum_{p'}\sum_{m'}\sum_t(Boc_{p'm'}^t \times BOQ_{p'm'}^t)\} + \{\sum_d \sum_t (F_d \times Ec_d^t)\}+\sum_{p'}\sum_w \sum_t (F_d \times Kc_{p'w}^t)\}+\{\sum_m F_{cm} \times F_m$$

$$+\sum_{m'} Fc_{m'} \times F_m$$

$$+\sum_w Fc_w \times F_w\} +\{\sum_{p'}\sum_w \sum_m \sum_t (Ppc_{p'wm'}^{pt}$$

$$PN_{p'wm}^t)+\sum_{p'}\sum_w \sum_{m'}\sum_t (Ppc_{p'wm'}^t \ X \ PN_{p'wm'}^t)+\sum_{p'}\sum_d \sum_m \sum_t (Ppc_{p'dm}^t \quad PN_{p'dm}^t)+\sum_{p'}\sum_d \sum_{m'}\sum_t (Ppc_{p'dm'}^{pt}$$

$$PN_{p'dm'}^t)+\sum_{p'}\sum_{cp} \sum_w \sum_t (Ppc_{p'cpw}^{pt} \quad PN_{p'cpw}^t)+\sum_{p'}\sum_{chp} \sum_w \sum_t (Ppc_{p'chpw}^{pt}$$

$$PN_{p'chpw}^t)+\sum_{p'}\sum_{cp} \sum_d \sum_t (Ppc_{p'cpd}^{pt} \quad PN_{p'cpd}^t)+\sum_{p'}\sum_{chp} \sum_d \sum_t (Ppc_{p'chpd}^{pt}$$

$$PN_{p'chpd}^t)\}+\sum_w \sum_m \sum_{p'}\sum_{r_{mw}} \sum_t Dc_{wmp'}^t \quad Q_{p'mw}^{tr_{mw}} +\sum_w \sum_{m'}\sum_{p'}\sum_{r_{m'w}} \sum_t Dc_{wm'p'}^t$$

$$Q_{p'm'w}^{tr_{m'w}} +\sum_d \sum_m \sum_{p'}\sum_{r_{md}} \sum_t Dc_{dmp'}^t \quad Q_{p'md}^{tr_{md}} +\sum_d \sum_{m'}\sum_{p'}\sum_{r_{m'd}} \sum_t Dc_{dm'p'}^t \quad Q_{p'm'd}^{tr_{m'd}} +\sum_d \sum_w \sum_{p'}\sum_{r_{wd}} \sum_t Dc_{dwp'}^t$$

$$Q_{p'wd}^{tr_{wd}} +\sum_{cp} \sum_w \sum_{p'}\sum_{r_{wcp}} \sum_t Dc_{cpwp'}^t \quad Q_{p'wcp}^{tr_{wcp}} +\sum_{chp} \sum_w \sum_{p'}\sum_{r_{wchp}} \sum_t Dc_{chpwp'}^t$$

$$Q_{p'wchp}^{tr_{wchp}} +\sum_{cp} \sum_d \sum_{p'}\sum_{r_{dcp}} \sum_t Dc_{cpdp'}^t \quad Q_{p'dcp}^{tr_{dcp}} +\sum_{chp} \sum_d \sum_{p'}\sum_{r_{dchp}} \sum_t Dc_{chpdp'}^t \ X \ Q_{p'dchp}^{tr_{dchp}}$$

4 Method of Solution:

The paper introduces an enhanced version of the RDA, known as the Improved IMORDA, to efficiently address the proposed problem. The RDA is a meta-heuristic inspired by the life-activities of Red-Deer during the breeding-season, incorporating behaviours such as roaring, fighting, and mating. It involves six controlling parameters such as: Maxit which is Maximum-Number-of-Iterations, nPop which is Population-Size), nMale i.e number-of-male-red-deer, Alpha (% of mating in a harem), Beta (% of mating in a random-harem), and Gamma (% of commanders).

In this proposed-IMORDA, the value of the parameters, particularly Alpha, Beta, and Gamma, are determined using specific rules related to the mating processes. This modification not only reduces the number of controlling-parameters but also improves the effectiveness of the algorithm in generating efficient solutions compared to the original concept.

To incorporate the terminology of red deer in the algorithm, two groups are defined: male red deer (comprising stags and commanders) and hinds. The number of commanders, which represents the top solutions and plays a crucial role in the intensification phase, is determined by considering both diversification and intensification properties. The % of commanders among all males is updated using a formula that depends on the current iteration and the maximum-number-of-iterations.

Gamma = (0.1+0.9*(it/ Maxit)) where, it: current iteration-of-the-algorithm,

Similarly, the values of Alpha and Beta, which influence the mating-operators, are updated based on the iteration number and to calculate Alpha and Beta we have the formula:

Alpha = (0.4+0.6*(it/ Maxit)) and Beta=1- Alpha

An easily-adaptive-technique is used to run the search-mechanism of the algorithm more effectively, allowing for a well-tuned selection of search-phases. The IMORDA ensures effective exploration and exploitation of the search space towards optimal solutions.

The key advantage of the IMORDA lies in its reduced number of controlling parameters and its improved search mechanism. With only 3-simple parameters, the algorithm provides a more streamlined and efficient approach to finding optimal solutions. By dynamically updating the other parameters based on the progress of the algorithm, the IMORDA optimizes the search process and demonstrates its effectiveness in generating high-quality solutions.

Results and Discussions:

To assess the effectiveness as well as Robustness of the discussed model, a comprehensive sensitivity-analysis was done on several key parameters. This analysis aimed to examine the impact of variations in parameters such as holding cost, FC of warehouses, demand for pharmaceutical-products, and DC.

Sensitivity analysis on the IHC of pharmaceutical-products at warehouses.

Table 1:

Cases	$Ihc^{t}_{wp'}$	F1	F2	F3
C1	150000	2923146	22964.62	312253.7
C2	200000	2925637	22964.62	312253.7
C3	250000	2794355	22964.62	312253.7
C4	300000	2983753	22964.62	312253.7

The sensitivity analysis involved systematically varying these parameters within a range of values to observe how they influenced the overall performance of the model. By adjusting the HC, which represents the cost associated with storing-pharmaceutical-products, the researchers could evaluate its effect on the total cost and optimize inventory management strategies.

Sensitivity-analysis on the FC of warehouses.

Table 2:

Cases	Fc_{w}	F1	F2	F3
C1	15000	2726437	22934.62	332442.7
C2	20000	2773481	22934.62	332442.7

C3	25000	2826145	22934.62	332442.7
C4	30000	2858134	22934.62	332442.7

Similarly, by varying the FC of warehouses, which represents the expenses incurred in establishing new warehouse facilities, the researchers could determine the optimal-number and locations of warehouses within the supply-chain-network.

Sensitivity-analysis on the demand for products in warehouses.

Table 3:

Cases	$K^{t}_{p'wm'}$	F1	F2	F3
C1	15000	2822619	21645.23	333257.1
C2	20000	2925537	22764.62	335443.7
C3	25000	2757711	22355.53	334738.7
C4	30000	2768135	21546.53	323527.6

The demand for pharmaceutical products was also subjected to sensitivity analysis to explore its impact on various performance metrics such as delivery time, cost, and customer satisfaction. By studying different demand scenarios, the researchers could identify the optimal allocation and distribution strategies to meet the varying needs of customers.

Sensitivity analysis on the DCs at warehouses.

Table 4:

Cases	$Dc^{t}_{wmp'}$	F1	F2	F3
C1	15000	2675364	23167.46	312253.7
C2	20000	2746377	22686.34	312253.7
C3	25000	2675432	21454.72	312253.7
C4	30000	2764598	20185.71	312253.7

Furthermore, the sensitivity analysis examined the influence of DCs, which encompassed transportation expenses and other logistical factors. By adjusting these costs, the researchers could assess their impact on the overall efficiency of the pharmaceutical-supply-chain network and identify potential cost-saving opportunities.

5 Conclusions:

The study presented a comprehensive analysis of a multi-period, multi-echelon, and multi-product PSCN, considering various uncertain parameters and the use of multimodal transportation. The inclusion of these uncertain parameters adds a realistic aspect to the model, making it more applicable to real-world scenarios.

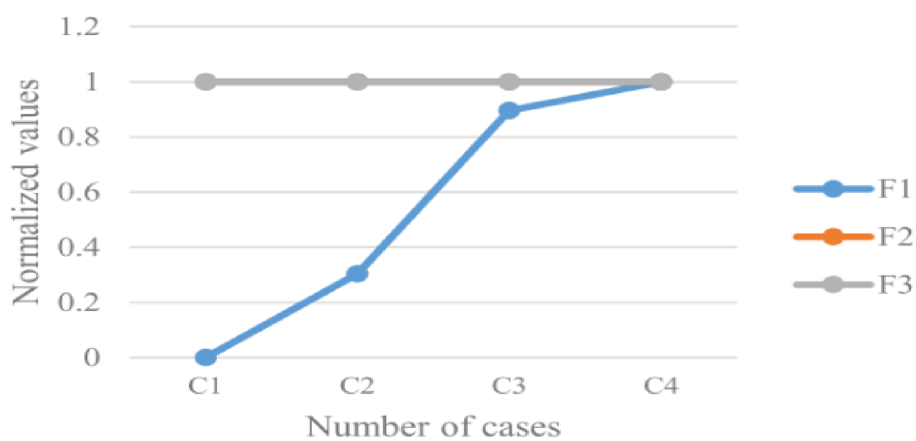
To assess the performance of the proposed-model, sensitivity-analyses were conducted on objective-functions, which are metrics used to evaluate the effectiveness and efficiency of the supply-chain-network. Sensitivity-analysis involves systematically varying the input parameters and observing the resulting changes in the objective functions.

By conducting sensitivity analyses on the objective functions, the researchers gained valuable insights into how the system responds to different parameter values. This analysis helped identify the critical factors that have a significant impact on the overall performance of the PSCN. For example, changes in purchasing-costs products, capacity-limitations of warehouses and distribution-centres, and transportation costs can greatly affect the objective functions, such as TC, delivery-time, and system-reliability.

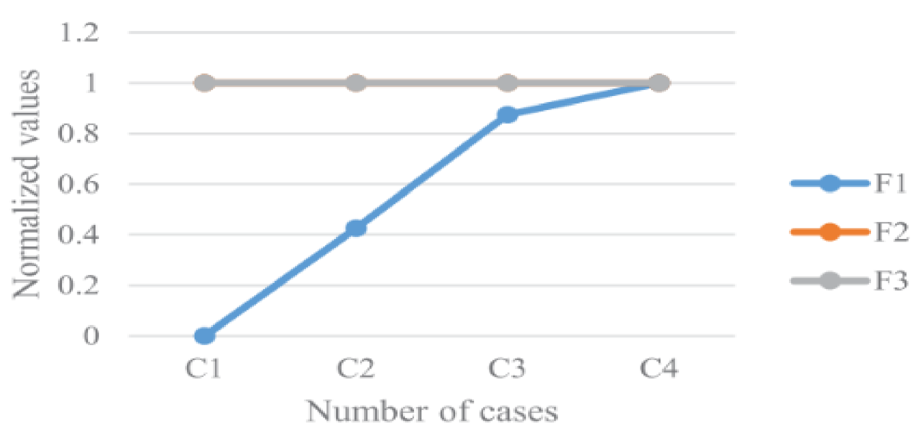
The sensitivity-analyses provided a deeper understanding of the behaviour of the objective functions under different scenarios and parameter settings. This knowledge enables decision-makers to make informed decisions and implement strategies that optimize the performance of the pharmaceutical-supply-chain-network. By identifying the key factors influencing the objective functions, potential areas for improvement and optimization can be identified and targeted.

Overall, the sensitivity analyses conducted in this study enhance the understanding of the complex interactions and dependencies within the pharmaceutical-supply-chain-network. They provide valuable insights into the system's behavior and help guide decision-making processes to improve efficiency, reduce costs, and enhance the overall performance of the supply chain network. Behaviour of objective functions based on sensitivity-analyses on:

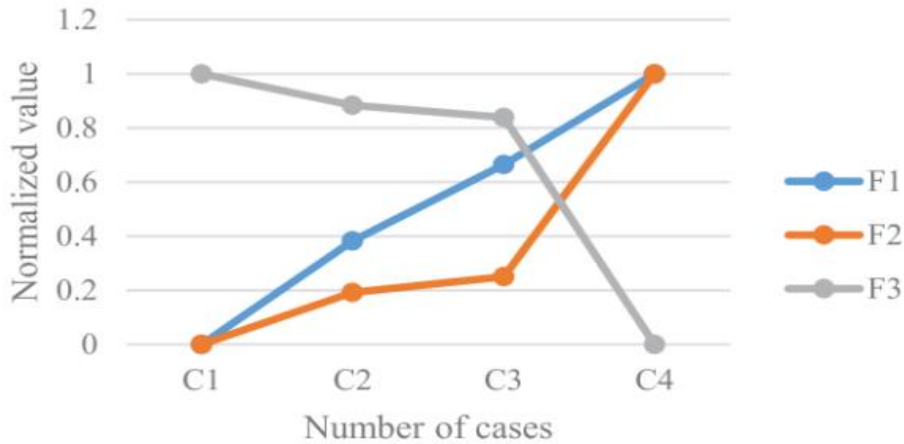
The IHC of products at warehouses



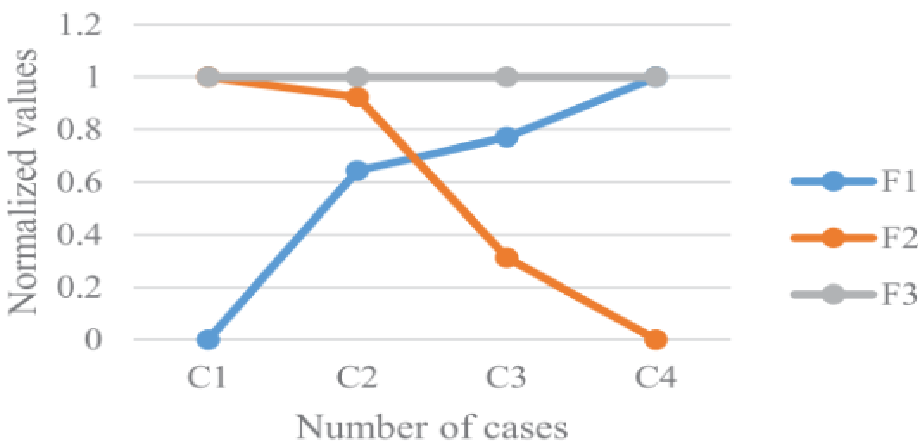
The FC



The demand of products



The DC



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