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Sophisticated Design and Integrative Modeling of Sustainable Environmental Practices in Contemporary Pharmacy and Pharmaceutical Industries

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Abstract

Several firms prioritize sustainability in the Pharmacy and Pharmaceutical Practices (PPP) to enhance the industry's lifespan and societal reputation. To compete effectively in foreign markets, PPP businesses must enhance their competencies. They must choose certain levels of commitment to sustainable initiatives to maintain their supplier networks. This research introduces a multi-objective approach to developing a PPP transportation system based on the fundamental sustainability principles: financial, ecological, and societal. This model assists managers in making strategic and technical decisions regarding the PPP Distribution Chain (DC), including the capacity of primary and regional DC and the movement of pharmaceuticals within the network. Reducing expenses while enhancing societal well-being and mitigating adverse environmental impacts results in environmentally friendly choices. The NSGA-II technique was utilized to identify the Pareto-analysis for the given method concerning function objectives. Darupakhsh Distribution Corporation was selected to evaluate the model using actual PPP data. The findings of the tailored model for the scenario elucidate the strategic and technical choices inside the PPP DC.

Keywords:

Sustainable environment, pharmacy, pharmaceutical practices, supply chain.

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Introduction

Climate change is the paramount healthcare challenge of the 21st century (Zang et al., 2021). Global warming is expected to increase the prevalence of vector-borne illnesses, heat stress, and hunger. Some co-morbid groups are expected to be disproportionately impacted by severe environmental circumstances. Asthma

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patients have more frequent exacerbations due to subpar air quality (Kumar et al., 2023). The rising illness load will result in heightened pharmaceutical usage and demand. Pharmacy and Pharmaceutical Practices (PPP) affect the surroundings from the stages of drug creation until their disposal.

Beyond the carbon footprints of PPP businesses, improper disposal of pharmaceuticals results in water pollution and animal bioaccumulation (Freitas & Radis-Baptista, 2021). Waste disposal was anticipated to decompose active pharmaceutical chemicals to an acceptable danger threshold. Recent investigations indicate that feminized fish have been linked to water tainted with estrogen-containing contraception. Heightened pharmaceutical usage will exacerbate the environmental repercussions of the pharmacological lifecycle (Caban & Stepnowski, 2021). Healthcare trainees and professionals globally must recognize these concerns and promote environmentally sustainable medication manufacture and disposal (Neelima et al., 2024). Healthcare professionals, including doctors, nurses, and pharmacies, play a crucial role in climate-related mitigation, instruction, and policy (Dupraz & Burnand, 2021). Environment, Healthcare, Security, and Sustainability (EHS&S) pertains to the measures implemented to safeguard the well-being of workers and the public and preserve the natural world (Kodric et al., 2021). Effective EHS&S management necessitates establishing systems and procedures to evaluate and mitigate the risks associated with environmental effects and health and safety threats (Mazutis et al., 2022).

In developing environmentally friendly Distribution Chains (DC), organizations must assess the effects of their activities on society as a whole due to escalating environmental, regulatory, and social concerns (Hummels & Argyrou, 2021). Sustainability is founded on human growth's financial, ecological, and social components. Numerous firms have adopted specific levels of commitment to sustainability policies to maintain their supplier networks. Academic institutions and diverse sectors of the global economy have adopted sustainable PPP practices, including energy-efficient gadgets, renewable resource utilization, recycling, environmentally friendly purchases, minimized packaging, carbon emission accounting, social responsibility, and worker recognition, to promote sustainability in managing the DC (Bai et al., 2021). Certain studies emphasize the environmental dimension, while the social dimension of the supply chain continues to be overlooked (Llopiz-Guerra et al., 2024).

Pharmaceutical companies are compelled by formidable regulating and marketplace pressures to reevaluate their production and distribution methods while reimagining the DC’s role in fostering strategic growth, brand differentiation, and economic value within the healthcare system (Veera Boopathy et al., 2024; McGarity & Shapiro, 2020; Wang, 2024). The pharmaceutical DC requires greater attention than other sectors due to customized client demand, market dynamics, fragile networks, and regulatory laws. Ensuring the uninterrupted delivery of medications to consumers at optimal pricing, with minimal interruptions, low deficits, and no mistakes, is crucial in pharmaceutical logistics. This project aims to create a PPP DC based on the fundamental sustainability principles: economic, environmental, and social (Alshemari et al., 2020). This model assists in making strategic and technical choices on the pharmaceutical DC, including the ability of primary DC facilities and the quantity and capacity of local DC. These choices are taken to reduce expenses and negative environmental impacts while enhancing societal well-being (Henderson & Loreau, 2023).

Background to Pharmacy and Pharmaceutical Practices

Pharmaceutical spending is constantly rising, making the PPP sector a substantial portion of the national Gross Domestic Product (GDP) today (Basak et al., 2022). Pharmaceutical businesses are pressured to provide conditions that facilitate growth in domestic and foreign markets. Research on the pharmaceutical DC is essential for all nations (Yu et al., 2021). Figure 1 illustrates that a pharmaceutical DC generally consists of a

few of the following kinds of components: (i) primary production, such as contractor facilities; (ii) secondary production, including suppliers facilities; (iii) the marketplace storage facilities or distribution focuses; (iv) distributors; and (v) merchants or health care institutions (Sunny et al., 2020). The primary production generates active ingredients using chemical processes to synthesize molecules (Clementine et al., 2014). Additional manufacturing encompasses procedures used for goods derived from active ingredients produced at the original site, culminating in the packaging of completed goods. Distributors play a significant role in this sector.

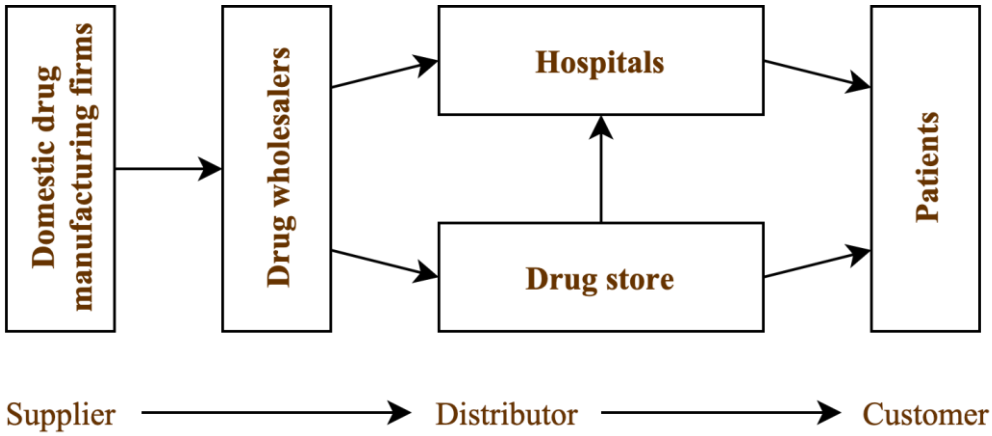

Figure 1. Pharmaceutical supply chain

Several products and extended timeframes characterize the pharmaceutical DC system. The pharmaceutical supply chain comprises four echelons, featuring multiple secondary drug production facilities, primary DCs, local DCs, and client zones (such as healthcare facilities, clinics, and drugstores), with the transfer of drugs occurring among local DC facilities (Moran et al., 2024).

Bekoe et al. conducted a study on the pharmaceutical business and proposed an effective technique for assessing and selecting providers inside a pharmaceutical company in Ghana (Bekoe et al., 2020). The study employed the analytical hierarchy technique to choose the most suitable raw materials suppliers for the anti-malarial medicine case study. Blossey et al. examined the internal supply chain of a multinational PPP firm distinguished by a multi-site and multi-stage operational framework (Blossey et al., 2022). They tackled difficulties at three tiers: tactical, strategic, and practical. They concentrated on the tactical level, established a model and instance that encapsulated challenges, and connected concerns to business matters.

Kochakkashani et al. introduced a comprehensive method to enhance the profits of the supply chain for healthcare supplies amidst unpredictability (Kochakkashani et al., 2024). This model incorporates many reasonable presumptions regarding medical device logistics, including numerous goods, different periods, different echelons, and a constrained warehousing lifetime. Reverse logistics for expired and faulty items are anticipated to address environmental considerations and customer demands while achieving economic benefits. An efficient memetic method, including adaptable changing neighborhood searching as its local searching heuristic, was devised to address this challenge. Zandkarimkhani et al. introduced an integer linear programming approach to create a pharmaceutical DC system (Zandkarimkhani et al., 2020). This approach proposes making numerous choices about strategic problems, including establishing manufacturing plants for PPP and primary or regional distribution hubs, while optimizing the flow of materials over a mid-term planned horizon as tactical choices.

A significant difficulty for contemporary manufacturing firms is the measurement and regulation of CO2 emissions throughout the supply chain due to the growing apprehension over the adverse environmental effects of corporate operations. Mamashli et al. developed a credit-based fuzzy computational framework to lay out a logistics system in an unpredictable environment (Mamashli et al., 2021). The model concurrently lowers ecological consequences and management expenses to balance the two. A well-recognized and reputable ecological effect evaluation metric, namely the CO equivalents index, was employed to evaluate the ecological impact of the relevant logistics network.

Ahmadini et al. developed a generalized multi-objective computational programming approach to supply chain planning that incorporates the three elements of sustainability (Ahmadini et al., 2021). This study examines the economic dimension of PPP by evaluating DC expenses. Machado et al. introduced a social indicator for evaluating tactical choices (Machado et al., 2020). This social indicator evaluates the influence of political and social variables on the company's success. The investigation used a real-life instance of a Portuguese battery manufacturer and reseller.

Environmental Sustainability in Pharmacy and Pharmaceutical Practices

Responsibility

Sustainable development in the PPP sector is a significant issue because of its possible effects on the environment, human wellness, and our planet's well-being. As medical professionals, pharmacists are integral to advancing and implementing Sustainable Development (SD). Pharmacy technicians might assume several roles in promoting SD within the pharmaceutical business.

- Pharmaceutical Oversight and Waste Minimization: Through the optimization of drug use, pharmacists instruct patients and healthcare professionals on the proper administration of pharmaceuticals, encompassing dose modifications, the avoidance of superfluous prescriptions, and the advocacy of cheaper alternatives.
- Medication Evaluation: Perform systematic medication evaluations to decrease the utilization of redundant or duplicative pharmaceuticals, lowering expenses and environmental repercussions.
- Appropriate Disposal: Instruct patients on suitable pharmaceutical disposal techniques to prevent environmental pollution. Numerous towns possess explicit regulations for the safe disposal of pharmaceuticals.
- Advocating for SD of Drug Practices: Urge pharmaceutical businesses to implement sustainable manufacturing practices to mitigate the environmental impacts of medicine manufacture.
- Advocate for Green Chemistry: Encourage the implementation of green chemistry concepts in the manufacturing of pharmaceuticals to reduce the utilization of hazardous materials and energy-demanding procedures.
- Eco-Friendly Pharmaceutical Practices: The Efficiency of Energy: Adopt energy-efficient techniques in pharmaceutical operations, including the utilization of energy-efficient appliances, optimization of illumination, and reduction of overall electrical consumption.
- Waste reduction: Reduce the utilization of disposable materials and promote the recycling of packing and other waste produced in pharmacies. The portion of Entoncraly handles practice for manufacturing packaging.

- Minimize Carbon Footprint: Prefer suppliers locally, when feasible, to minimize the environmental impacts of travel.
- Patient Instruction: To raise knowledge of the environmental impact and educate consumers on the ecological consequences of medications and their involvement in mitigating them through appropriate medication administration and disposal.

Steps to be Considered

Pharmacy organizations and individual pharmacists worldwide. The further actions to be considered are:

- Pharmacy organizations should promote broadening pharmacists' range of practice, emphasizing the enhancement of pharmacist-led activities and improving care access in underprivileged populations.
- Pharmacists can significantly mitigate healthcare concerns, including air pollution and climate change. Pharmacy organizations have to prioritize health-promoting activities and advocate for the involvement of pharmacists in these endeavors.
- Assessing the influence of PPP: Pharmacy organizations must prioritize evaluating the effects of pharmacy operations on patient satisfaction and public health. This entails investing in studies and assessments to assess the worth of pharmacy work and utilizing these results to guide policy and practice. Data and knowledge derived from pharmacy operations are crucial; via the FIP Globe Pharmaceutical Observation (GPO), FIP can assist members in assessing effect.
- Pharmacy organizations should prioritize cooperation with other medical experts and stakeholders to enhance PPP and patient outcomes. This entails establishing collaborations with physicians, nurses, and other healthcare professionals and interacting with legislators, payers, and consumers to advocate for the significance of pharmacy services.

Pharmacy organizations should prioritize enhancing patient-centered care by developing and employing tools and tactics that increase consumer communication and facilitate collaborative decision-making. This entails augmenting the function of pharmacists within collaborative approaches to care and allocating resources toward educational and training programs to empower pharmacists in these capacities.

Life Cycle Procedure

The complete life cycle of medications is often intricate and influenced by many social, environmental, and financial factors. It is crucial to comprehend the many phases of this life cycle to pinpoint the origins and manifestations of sustainability challenges.

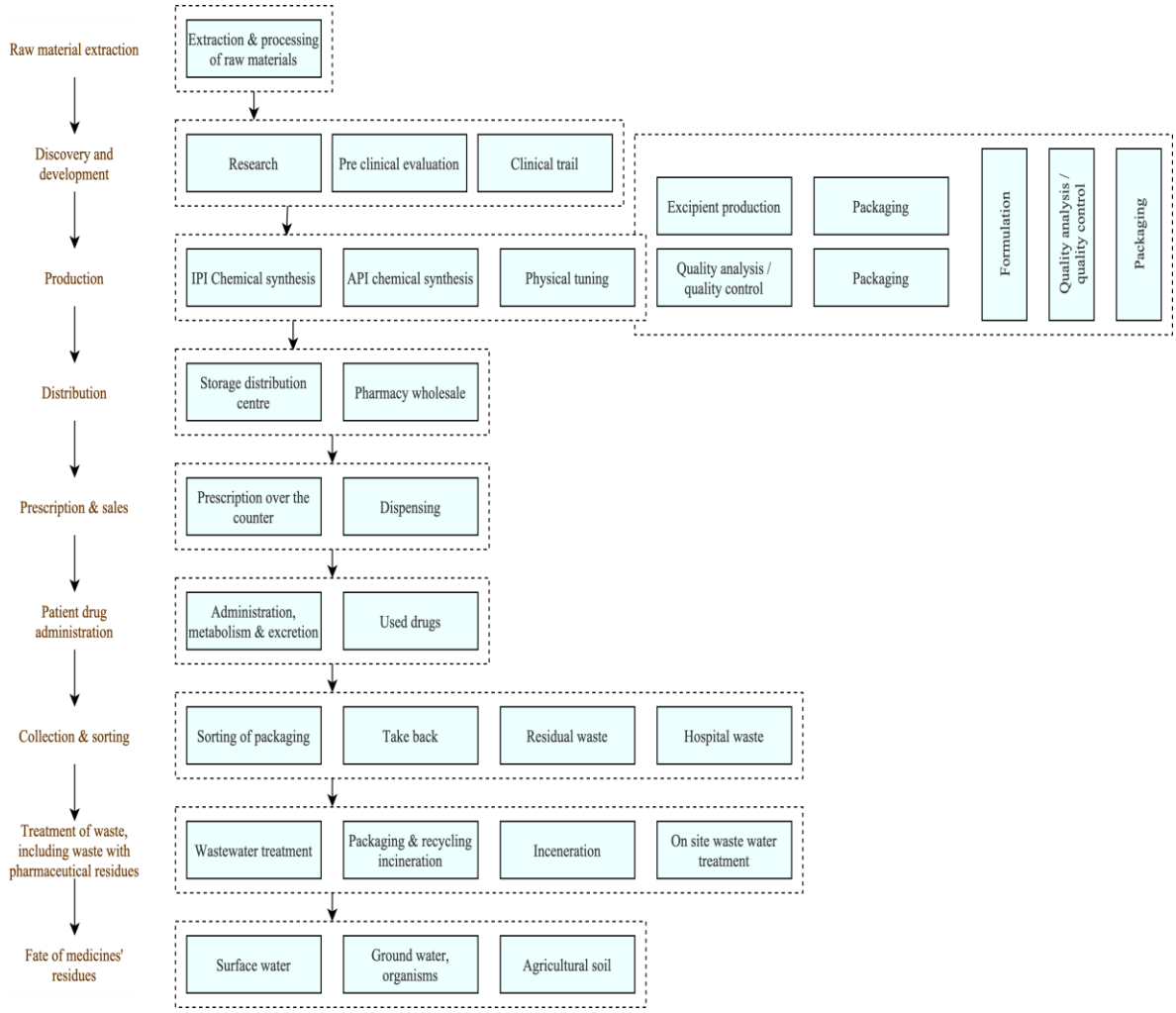

Figure 2. Lifecycle assessment process

The comprehensive framework considers every stream and procedure across the pharmaceutical life cycle (LC), from inception to disposal. Eight sequential steps have been discovered, encompassing many sub-procedures (Figure 2). The many procedures within phases constitute the Technosphere (TS). Every process possesses inputs that give the framework and results that exit it. The motions (i.e., path in the illustration) signify interactions inside the TS and among the Ecospheres (ES) (i.e., surroundings) and TS. Stage nine constitutes a component of the ES, incorporating inputs from the TS.

Extraction of materials: Initially, materials are sourced from the surroundings to serve as inputs in the next phases of the LC.

Detection and growth: The secondary phase involves the detection and verification of illness-changing or therapeutic goals, like amino acids or genes, followed by constructing pharmaceuticals, which includes establishing an appropriate, secure, and effective drug through early-stage and clinical experiments, as well as chemical process invention.

Production: The third phase entails extensive manufacturing, commencing with the chemical manufacturing of the inert chemical substances (Intermediary Pharmaceutical Items (IPI)) that constitute the foundational elements of the Additional Pharmaceutical Items (API). Following physical adjustment and quality assessment/control, the medication and excipients (e.g., chemicals such as binders or flavorings) are

formed into a stable form for administration. The concluding phase involves a secondary quality evaluation and control, followed by the final packing of the pharmaceutical product. These phases occur in various geographical places worldwide.

Dissemination: The fourth step involves delivering pharmaceutical items to hospital pharmacies and pharmacies, including intermediary entities such as storage and bulk distribution facilities. Good dispersion function guarantees the quality and authenticity of medicines across the distribution network, including heat-sensitive medical items.

Prescription and revenues: In the final phase, drugs are sold by prescription or without a prescription and administered to the client.

Administration of medication to patients. The sixth step encompasses two potential pathways: 1) the ingestion, metabolisms, and elimination of the pharmaceutical by individuals, and 2) unused medicines resulting from alterations in therapy or surplus pharmaceuticals owing to excessive dispensing and expired products.

Gathering and categorization: Pharmaceutical goods are gathered and categorized. If the medicine is utilized, just the packaging is separated. Surplus, undesirable, or expired medications are gathered via take-back programs at pharmacies, designated garbage at medical institutions, or dropping locations at urban rubbish gathering sites. Garbage is appropriately managed through secure transport to incinerator facilities and specialized packaging reuse. Alternative, less appropriate disposal methods include residual trash (i.e., medicines combined with home garbage for urban solid waste management), wastewater (i.e., pharmaceuticals disposed of via toilets), and general hospital trash.

Analysis of garbage, like waste containing pharmaceutical compounds. The next stage encompasses the management of trash, including solvent waste generated during extraction and garbage containing pharmaceutical residues, as well as garbage analysis. Solid wastes are burnt or reused. The body's cells eliminate pharmaceutical leftovers, comprising the active pharmaceutical ingredient and its byproducts. Gels and creams are removed by showering, handwashing post-application, and laundering of garments. The sewage system sends urine and washed-off active pharmaceutical ingredients to the wastewater treatment facility. Wastewater from manufacturing facilities and institutions is generally treated or sent through the drainage system to the treatment plant. Certain nations have established regulatory rules for managing hospital effluents, including minimum standards for discharging such effluents into urban sewage systems.

Disposition of pharmaceutical residues: While not a traditional LC phase, this last step concentrates on the environmental impact of pharmaceutical leftovers. The release of APIs and byproducts into the natural world via garbage discharge from cleaning facilities, as standard treatment methods, inadequately eliminates pharmaceutical residues. Drug residues are deposited in surface waters, groundwater, sewage waste, or soil based on their chemical properties.

Results and Findings

The suggested sustainable DC approach to the pharmaceutical DC is tailored for a particular case investigation in Iran. Darupakhsh Company, a significant drug distribution entity in Iran, was selected to implement the approach. The examination of this organization reveals that it possesses one primary DC in Tehran and 20 regional distribution facilities across various cities throughout Iran. A strategic medicine was chosen based on the assessment of Darupakhsh Company specialists. Data were obtained from 20 significant clients of the

Clopidogrel medication. Figure 3 illustrates the potential configuration of the DC for the experimental investigation.

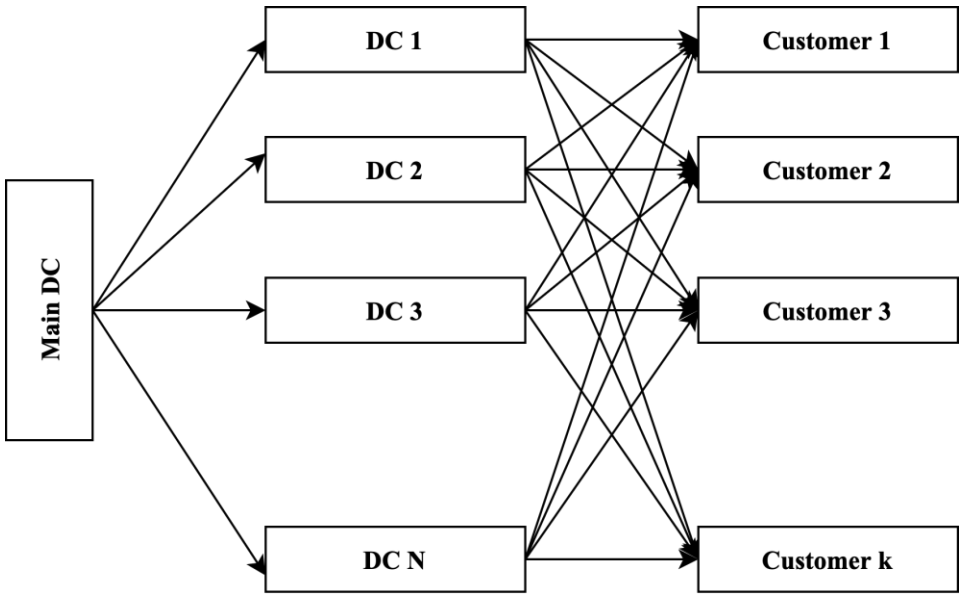

Figure 3. Pharmacy supply chain relationship

The data regarding the fixed costs associated with establishing the main delivery center and local distribution places, consumer zone demand statistics, the storage facilities of both primary and local shipping centers, and other necessary information have been acquired for the Clopidogrel drug by Darupakhsh Distribution Company. The subsequent phase involves determining the unit traveling price per 100 km by bus via consultations with shipping firms. The length of every pair of places is assessed using Google Maps. The shipping cost for every couple of required sites is computed. This research examines the CO2 indicator for trucks, a method of transportation, utilizing the Eco-index 99 datasets in the model construction. The CO equivalents index is a reliable metric that effectively quantifies the ecological effect and is utilised by academics. The third aim requires the joblessness rate of each city housing a regional distribution facility and the number of jobs generated at these centers. The joblessness ratio statistics 2016 were obtained from the Statistical Center of Iran. Additional characteristics not disclosed below are available upon demand.

To address the suggested approach through an actual scenario, the balanced total model is initially employed to effectively illustrate the contentious nature of operations and offer an appropriate Pareto function while not resulting in a singular answer. The resolution of the framework will ascertain the following: the neighborhood DC to be established, the volume of Clopidogrel dispatched from the primary DC to regional areas, and the Clopidogrel allocated to client areas.

In the subsequent phase of the work, the NSGA-II method was employed to derive the Pareto function for the suggested framework with three function objectives. The primary difference between NSGA and II lies in the listing mechanism. The listing procedure adheres to the rank and overcrowding distance criteria. The computational cost of the NSGA-II method for this kind of model is $3 \times npop^2$. The optimal answers on the Pareto front consist of 12 points identified in a single run, as seen in Figure 4. The red stars indicate the optimal quantity of goal functions during a run. The current run has a population size of 50 and 300 sessions.

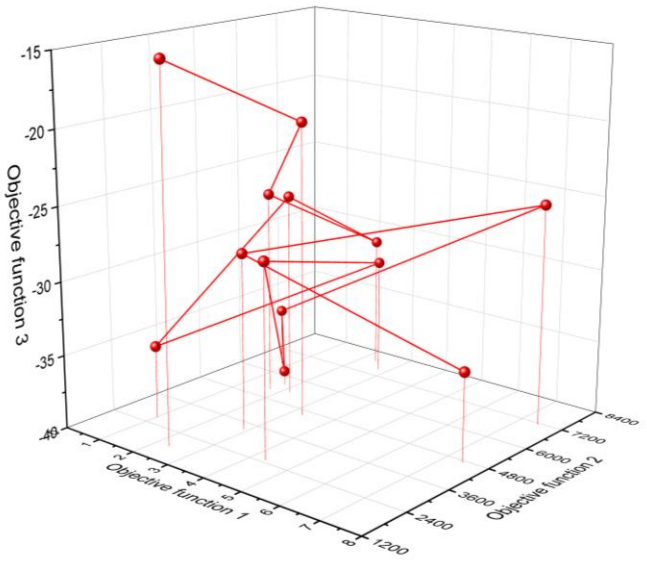

Figure 4. Pareto front objective operation analysis

The future of pharmacy is to enhance sustainability, and there is tremendous potential for joint efforts. There exists a significant potential and a corresponding duty to integrate sustainability as a prominent aspect of our organization. This presents a chance for creativity. Innovative technology is crucial for the PPP concerning green chemistry and related matters. In addition to regulatory creativity, it involves establishing frameworks and fostering circumstances that will steer markets in novel ways—finally, inventive techniques to transform the design of systems and advisory services.

Conclusion

Pharmaceutical expenditures are rising, becoming a substantial portion of national GDP. Pharmaceutical businesses are pressured to provide conditions that facilitate growth and competition in home and foreign markets. Another alteration in global competitiveness is that corporations choose specific levels of commitment to sustainable PPP policies to maintain their supplier networks. This study introduced a novel method for creating a pharmaceutical DC based on the fundamental sustainability principles: financial, ecological, and social. The first target function pertained to costs, aiming to decrease the expenses of delivering items from primary DC facilities to regional distribution centers and consumer zones. The secondary objective was to reduce carbon dioxide emissions from the DC—the third goal was to optimize social welfare by enhancing employment rates inside the pharmaceutical distribution system. Due to the benefits of the NSGA-II technique, including minimal computing demands, an elitist strategy, and a parameter-less sharing mechanism, as documented in the literature, this methodology is employed to attain the optimal solution. Darupakhsh Distributing Company, a leading drug distribution firm in Iran, has been selected to implement the approach. The ideal solutions on the Pareto front consisted of 12 points, from which managers selected the most suitable option based on corporate policy and discretion. This answer identified the active regional DC, the volume of Clopidogrel moved from the primary DC to the regional places, and the volume moved from the neighborhood centers to the client zones. Nineteen thousand two hundred five boxes of this medication must be transported to Ahvaz. The outcomes of the tailored model in this scenario illustrate the tactical and technical determinations inside the pharmaceutical DC. The resolution of the suggested model yields decisions on the capabilities of the primary DC, the number of nearby DCs, and their respective capacities. The methodology assists managers in determining the optimal locations for new DC based on three sustainability criteria.

The selection of primary and local DC facilities using this viable approach assists administrators of pharmaceutical DC firms in reducing expenses. It reduces CO emissions and confers environmental benefits. The findings of this study are beneficial for civilizations experiencing elevated rates of joblessness. The third objective function aids in selecting distribution centers requiring more manpower. The developed model for the pharmaceutical DC applies to other distribution systems featuring primary and regional DC with analogous linkages, such as those utilized for perishable items. This study examines several assumptions regarding accelerators. The environmental unpredictability is not taken into account. This model exclusively accounts for CO emissions in the environment. Additional implications are acknowledged, such as the energy consumed per product. This research considers the employment rate to optimize the social dimension of sustainability while recognizing issues such as labor laws, decent work, societal impact, human rights, and product accountability. Recommendations for future research involve evaluating the model with other PPPs and under ambiguous conditions and including alternative indicators of social and ecological dimensions of sustainability in the model's objectives. Utilizing other strategies to solve this model facilitates the comparison of findings in subsequent investigations.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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