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RESEARCH ARTICLE

The multi-objective solid transshipment problem with preservation technology under fuzzy environment

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Abstract

To evaluate the efficiency of the preservation technology in the transshipment problem for transporting perishable products throughout the entire distribution system. A mathematical model for multi-objective solid transshipment problem incorporating preservation technology is formulated and a numerical example is provided to validate the effectiveness of this proposed model. To make the problem realistic, all the parameters are considered under a neutrosophic fuzzy environment. Weighted tchebycheff metrics programming has been used to obtain the Pareto-optimal solution of the proposed model. Comparative analysis has been done for multi-objective solid transshipment problems with and without preservation technology. Additionally, comparative analysis has been made for both multi-objective solid transshipment and multi-objective solid transportation problems with and without the inclusion of preservation technology. Also, comparative analysis has been made for multi-objective solid transportation problems with and without the inclusion of preservation technology under the Neutrosophic and Pythagorean fuzzy environments. Optimum Solutions obtained for a given numerical example using the prescribed method reveal that the multi-objective solid transshipment problem with preservation technology gives the minimum deterioration rate and higher transportation cost than the case without preservation technology. While the transportation cost increases, incorporating preservation technology into the transshipment problem enhances both the quality and quantity of perishable items in the distribution system. The efficiency of the multi-objective solid transshipment problem with preservation technology under a neutrosophic fuzzy environment is not yet investigated in the literature.

Keywords: Solid transshipment problem, Multi-objective transshipment problem, Preservation technology, Neutrosophic fuzzy environment, Weighted tchebycheff metrics programming.

Introduction

In recent years, the demand for fresh products has been steadily increasing due to consumer awareness of health and nutrition, along with a growing preference for sustainable and natural food choices. The transportation problem is one of the special types of linear programming problem in which perishable goods like foods, fruits, vegetables, flowers, medicines, and blood are transported from source to destination with subject to supply and source constraints. It was originally developed by Hitchcock in 1941. Due to, the unavailability of perishable goods and natural disasters, the supply of goods to customers may be delayed. To address these challenges, the transshipment problem, first introduced by Orden (1956), involves the transportation of perishable goods through intermediate points before reaching their destination. In some cases, both supply and destination points act as transshipment points. Perishable items can deteriorate during long transshipment time, which may lead to their expiration before reaching the customer. As a result, customers often hesitate to order such items from a particular company and may prefer to purchase them from other companies. So, industries and companies must find effective ways to manage the distribution of these items. By implementing certain preservation technologies, such as temperature control, airtight packaging, ice packaging, and deep freezing systems, companies can maintain the quality of the items, reduce economic losses, and enhance customer satisfaction. However, an investment in preservation technology increases the preservation

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cost which depends on factors such as the quantity of transported items, shipping time and preservation mode. As the cost increases, the level of deterioration decreases due to the implementation of preservation technology (PT). Consequently, the items can be sold at a higher price, leading to greater profits, which help to prevent economic losses. Pervin *et al*. applied the preservation technology in an inventory model for deterioration items to reduce rate of deterioration (Pervin *et al*., 2020).

In a transshipment problem, various types of conveyances, such as trucks, freight trains, ships, and cargo flights, are used to transport perishable items from one place to another. In addition to the source and demand constraints, conveyance constraints are incorporated into the classical transshipment problem which is known as the solid transshipment problem. In recent years, a group of researchers has analyzed various aspects of this problem under different circumstances. Ghosh *et al*., (2021) proposed a solid transportation problem within a fully intuitionistic fuzzy environment, incorporating fixed charges and multiple objectives. Roy *et al*., (2019) addressed a solid transportation problem with fixed charges, considering twofold uncertainty. Das *et al*., (2020) developed a solid transportation problem based on the p-facility location problem using a heuristic algorithm. For the economic policy in a transshipment problem, transportation costs, deterioration, and transportation time are considered during the movement of items from the source to various destinations. However, a single objective function is not enough to fully capture the complexity of the entire situation. Thus, the system addresses those economic factors by introducing a multi-objective optimization problem. Alp, S., & Ozkan, T. (2018) investigated the multi-objective transshipment problem using the goal programming method. AI-Sultan *et al*., (2022) created a multi-objective model for the transshipment problem based on various sizes of vehicles and routes. A solid transshipment problem involving multiple objectives is called a multi-objective solid transshipment problem. In recent years, few researchers have discussed only on multi-objective solid transportation problem. Roy and Midya (2019) discussed a multi-objective solid transportation problem with product blending under the intuitionistic fuzzy environment. Das and Roy solved the multi-item multi-objective solid transportation problem in an uncertain situation by using fuzzy programming. Trikolaee *et al*., (2019) investigated a multi-objective two echelon green routing problem for perishable products transported through intermediate depots. Extensive study is needed for multi-objective solid transshipment problems. The research gap of this study is given below.

To the best of our knowledge, the multi-objective solid transshipment problem for perishable items is not yet investigated in the literature. In this paper, a mathematical model for a multi-objective solid transshipment problem under preservation technology is formulated to reduce the deterioration rate of transported perishable products. While using preservation technology, the preservation costs are included in the overall transportation cost, which leads to an increase in the total cost. Engine-based freezing system (one mode of preservation technology) is incorporated in this proposed model to reduce the deterioration rate and increase the lifetime of such items during the time of transportation. Due to insufficient data and ambiguous situations, all the parameters of the proposed model cannot be considered as precisely. Zadeh first introduced fuzzy set theory (FS) in which the membership function lies between 0 and 1. Ghosh *et al*. developed a multi-objective transportation problem for perishable items with engine engine-based freezing system (one mode of preservation technology under a Pythagorean fuzzy environment. Extension of fuzzy set, Pythagorean fuzzy set cannot handle inconsistent and intermediate information. To address these issues, Smarandache introduced a neutrosophic set to which truth, falsity, and indeterminacy membership functions belong. In this paper, a multi-objective solid transshipment problem with an engine-based system (one of the preservation modes) under a trapezoidal neutrosophic fuzzy environment with transportation cost, time, and deterioration rate is considered as objective functions have been discussed. All the parameters in this model are considered trapezoidal neutrosophic fuzzy numbers. Consequently, the proposed model transformed into the deterministic model by utilizing the ranking function. Weighted Tchebycheff metrics programming is applied to find the optimal solution of the deterministic of the proposed model. Numerical examples have been discussed to show the effectiveness of this study.

The remaining parts of the paper are described as follows: Section 2 presented definitions of neutrosophic fuzzy numbers. Section 3 defines notations and assumptions. Section 4 describes the mathematical formulation of a multi-objective solid transshipment problem with preservation technology in a neutrosophic fuzzy environment and the deterministic model of our proposed model. Section 5 presents the solution procedures for the formulated model. Section 6 describes the numerical example and section 7 provides the results and discussions. Section 8, presents the conclusion and future research.

Methodology

Preliminaries

Definition 2.1.1 $\tilde{S}$ In a universal set E is called a single-valued neutrosophic and it is defined by $\tilde{S}=\{\langle e,T_{\tilde{S}}(e),I_{\tilde{S}}(e),F_{\tilde{S}}(e)\rangle : e\in E\}$ where truth, Indeterminacy, and Falsity membership functions and satisfies the condition $0\le T_{\tilde{S}}(e)+I_{\tilde{S}}(e)+F_{\tilde{S}}(e)\le 3\forall e\in E$ (Kalaivani *et al*., 2023).

Definition 2.1.2 A single valued trapezoidal neutrosophic number $\tilde{S}$ (SVTrNN) on a real line set and is defined by $\tilde{S} = \{\langle s_1, s_2, s_3, s_4 \rangle : w_{\tilde{S}}, u_{\tilde{S}}, v_{\tilde{S}}\}$ *where* $w_{\tilde{S}}, u_{\tilde{S}}, v_{\tilde{S}} \in [0,1]$ with the condition $s_1 \le s_2 \le s_3 \le s_4$, whose truth, indeterminacy, falsity membership functions are follows

$$T_{\tilde{S}^F}(e) = \begin{cases} w_{\tilde{S}} \dfrac{e - s_1}{s_2 - s_1} & s_1 \le e \le s_2 \\ w_{\tilde{S}} & s_2 \le e \le s_3 \\ w_{\tilde{S}} \dfrac{s_4 - e}{s_4 - s_3} & s_3 \le e \le s_4 \\ 0 & \text{otherwise} \end{cases}$$

$$I_{\tilde{S}^F}(e) = \begin{cases} \dfrac{s_2 - e + u_{\tilde{S}}(e - s_1)}{s_2 - s_1} & s_1 \le e \le s_2 \\ u_{\tilde{S}} & s_2 \le e \le s_3 \\ \dfrac{s_3 \aleph e \quad u_{\tilde{S}}(s_3 \quad e)}{s_4 - s_3} & s_3 \le e \le s_4 \\ 1 & \text{otherwise} \end{cases}$$

$$F_{\tilde{S}^F}(e) = \begin{cases} \dfrac{s_2 - e + v_{\tilde{S}}(e - s_1)}{s_2 - s_1} & s_1 \le e \le s_2 \\ v_{\tilde{S}} & s_2 \le e \le s_3 \\ \dfrac{e \aleph s_3 \quad v_{\tilde{S}}(s_3 \quad e)}{s_4 - s_3} & s_3 \le e \le s_4 \\ 1 & \text{otherwise} \end{cases}$$

(Kalaivani *et al.*, 2023)

Definition 2.1.3 Let $\tilde{S} = \{\langle s_1, s_2, s_3, s_4 \rangle : w_{\tilde{S}}, u_{\tilde{S}}, v_{\tilde{S}}\}$ be a SVTrNN, then the score function $S(\tilde{S})$ is defined as $S(\tilde{S}) = \frac{1}{12}(s_1 + s_2 + s_3 + s_4)(2 + w_{\tilde{S}} - u_{\tilde{S}} - v_{\tilde{S}})$ (Kalaivani *et al.*, 2023).

Mathematical Model for multi-objective solid transshipment problem with preservation technology under neutrosophic environment

This section provides a list of notations along with their intended meaning and assumptions made in this proposed model. Subsequently, a mathematical formulation is constructed for multi-objective solid transshipment problems with and without preservation technology under a neutrosophic environment.

Notations and Assumptions

g : sources $(l = 1, 2, ..., g)$
h : destinations $(p = 1, 2, ..., h)$
k : conveyance ($k = 1, 2, ...K$)
$\tilde{t}_{ü}$: single valued trapezoidal neutrosophic traveling time from the l^{th} source to p^{th} destination at k^{th} conveyance
$\tilde{c}_{ü}$: single valued trapezoidal neutrosophic transportation cost from the l^{th} source to p^{th} destination at k^{th} conveyance
$\tilde{d}_{lp}$: single valued trapezoidal neutrosophic deterioration rate from the l^{th} source to p^{th} destination at k^{th} conveyance
$\tilde{p}_{lp}$: single valued trapezoidal neutrosophic preservation cost from the l^{th} source to p^{th} destination at k^{th} conveyance
$\tilde{a}_l$: availability of the product at l^{th} source $(l = 1, 2, ..., g)$
$\tilde{b}_p$: demand of the product at p^{th} the destination $(p = 1, 2, ..., h)$
$x_{ü}$: quantity of products transported from the l^{th} source to p^{th} destination
$\eta_{ü}$: the binary variable takes a value of 1 if $x_{ü} \ge 0$ and 0 otherwise.
$\tilde{Z}_m$: objective function in a neutrosophic environment where $m = 1, 2, 3$
Z_m : the crisp value of an objective function $m = 1, 2, 3$
β_z : freezing function to reduce the deterioration rate in %

Mathematical Formulation

Multi-objective solid transshipment problem with preservation technology under neutrosophic environment

The mathematical model for multi-objective solid transshipment problem with preservation technology under a neutrosophic environment has been formulated as follows:

$$Min\ \tilde{Z}_1(x) = \sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K} \tilde{c}_{lpk} x_{lpk} + \sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K} \beta_z \tilde{t}_{lpk} \tilde{p}_{lpk} x_{lpk} \tag{1}$$

$$Min\ \tilde{Z}_2(x) = \sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K} \tilde{t}_{lpk} \eta_{lpk} \tag{2}$$

$$Min\ \tilde{Z}_3(x) = \sum_{l=1}^{ü+}\sum_{p=1}^{g+h}\sum_{k=1}^{K} \beta_z \tilde{d}_{lpk} x_{lpk} \tag{3}$$

Subject to

$$\sum_{p=1, l\ne p}^{g+h}\sum_{k=1}^{K} x_{lpk} - \sum_{l=1, l\ne p}^{g+h}\sum_{k=1}^{K} x_{plk} \le \tilde{a}_l, \quad l = 1, 2, 3, \ldots, g \tag{4}$$

$$\sum_{l=1, l\ne p}^{g+h}\sum_{k=1}^{K} (1 - \beta_z \tilde{d}_{lpk}) x_{lpk} - \sum_{l=1, l\ne p}^{g+h}\sum_{k=1}^{K} (1 - \beta_z \tilde{d}_{lpk}) x_{plk} \ge \tilde{b}_p, \quad p = g+1, g+2, \ldots, g+h \tag{5}$$

$$\sum_{l=1}^{g+h}\sum_{p=1}^{g+h} x_{lpk} \le \tilde{e}_k, k = 1, 2, 3, ...K \tag{6}$$

$$\eta_{ü} = \begin{cases} 0 & ü \quad _{ü} = 0 \\ 1 & ü \quad _{ü} > 0 \end{cases} \tag{7}$$

$$x_{lpk}, \eta_{lpk} \ge 0, l, p = 1, 2, 3, \ldots, g+h, k = 1, 2, ..., K \tag{8}$$

Multi-objective solid transshipment problem without preservation technology under Neutrosophic environment

The mathematical model for multi-objective solid transshipment problem without preservation technology under neutrosophic environment has been formulated as follows:

$$Min\ \tilde{Z}_1(x) = \sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K} \tilde{c}_{lpk} x_{lpk} \tag{9}$$

$$Min\ \tilde{Z}_2(x) = \sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K} \tilde{t}_{lpk} \eta_{lpk} \tag{10}$$

$$Min\,\tilde{Z}_3(x)=\sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K}\tilde{d}_{lpk}x_{lpk} \tag{11}$$

Subject to

$$\sum_{p=1,l\neq p}^{g+h}\sum_{k=1}^{K}x_{lpk}-\sum_{l=1,l\neq p}^{g+h}\sum_{k=1}^{K}x_{plk}\leq\tilde{a}_l,\quad l=1,2,3,\ldots,g \tag{12}$$

$$\sum_{l=1,l\neq p}^{g+h}\sum_{k=1}^{K}(1-\tilde{d}_{lpk})x_{lpk}-\sum_{l=1,l\neq p}^{g+h}\sum_{k=1}^{K}(1-\tilde{d}_{lpk})x_{plk}\geq\tilde{b}_p,\quad p=g+1,g+2,\ldots,g+h \tag{13}$$

$$\sum_{l=1}^{g+h}\sum_{p=1}^{g+h}x_{lpk}\leq\tilde{e}_k,k=1,2,3,\ldots K \tag{14}$$

$$\eta_{ü}\ =\begin{cases}0 & ü\ \ _{ü}=0\\ 1 & ü\ \ _{ü}>0\end{cases} \tag{15}$$

$$x_{lpk},\eta_{lpk}\geq 0,l,p=1,2,3,\ldots,g+h,k=1,2,\ldots,K \tag{16}$$

In model PT, the first objective function (1) represents the combined transportation cost and preservation charge for transporting items from l^{th} source to p^{th} destination at k^{th} conveyance. The preservation cost depends on the preservation function, preservation time, and the quantity of items $x_{ü}$ being transported. The second objective (2) defines the transportation time for transporting perishable items from l^{th} source to p^{th} destination at k^{th} conveyance. The third objective function (3) represents the deterioration rate of perishable items after applying preservation technology. The constraints (4),(5),(6),(7),(8) include the demand condition after applying preservation technology, total supply, conveyance capacity, and the non-negativity restriction of the variables.

In a model without PT, the equations (9), (10), (11) functions represent the transportation cost, time, and deterioration rate. The constraints (12),(13),(14),(15),(16) describe the supply, demand, conveyance capacity, and the non-negativity restriction of the variables.

Identical Deterministic Model

In the mathematical model, all the parameters are considered as trapezoidal neutrosophic fuzzy numbers due to handling uncertainty situations. The proposed model cannot be evaluated directly. Therefore, converting the model into the deterministic model by using ranking function as follows:

Deterministic Model for Multi-objective solid transshipment problem with preservation technology

$$Min\,\tilde{Z}_1(x)=\sum_{l=ü}^{g+h}\sum_{p=}^{g+h}\sum_{k=1}^{K}\Re(\tilde{c}_{lpk})x_{lpk}+\sum_{l=}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K}\beta_z\Re(\tilde{t}_{lpk})\Re(\tilde{p}_{lpk})x_{lpk} \tag{17}$$

$$Min ü\tilde{Z}_2(x)=\sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K}\Re\ \tilde{t}_{lpk}\ \ \eta_{lpk} \tag{18}$$

$$Min\,\tilde{Z}_3(x)=\sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K}\beta_z\Re(\tilde{d}_{lpk})x_{lpk} \tag{19}$$

Subject to

$$\sum_{p=1,l\neq p}^{g+h}\sum_{k=1}^{K}x_{lpk}-\sum_{l=1,l\neq p}^{g+h}\sum_{k=1}^{K}x_{plk}\leq\Re(\tilde{a}_l),\quad l=1,2,3,\ldots,g \tag{20}$$

$$\sum_{l=1,l\neq p}^{g+h}\sum_{k=1}^{K}(1-\beta_z\Re(\tilde{d}_{lpk}))x_{lpk}-\sum_{l=1,l\neq p}^{g+h}\sum_{k=1}^{K}(1-\beta_z\Re(\tilde{d}_{lpk}))x_{plk}\geq\Re(\tilde{b}_p),\quad p=g+1,g+2,\ldots,g+h \tag{21}$$

$$\sum_{l=1}^{g+h}\sum_{p=1}^{g+h}x_{lpk}\leq\Re(\tilde{e}_k),k=1,2,3,\ldots K \tag{22}$$

$$\eta_{ü}\ =\begin{cases}0 & ü\ \ _{ü}=0\\ 1 & ü\ \ _{ü}>0\end{cases} \tag{23}$$

$$x_{lpk},\eta_{lpk}\geq 0,l,p=1,2,3,\ldots,g+h,k=1,2,\ldots,K \tag{24}$$

Deterministic Model for Multi-objective solid transshipment problem without preservation technology

$$Min\,\tilde{Z}_1(x)=\sum_{l=1}^{ü+}\sum_{p=1}^{g+h}\sum_{k=1}^{K}\Re(\tilde{c}_{ü}\ \ )x_{ü} \tag{25}$$

$$Min ü\tilde{Z}_2(x)=\sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K}\Re\ \tilde{t}_{lpk}\ \ \eta_{lpk} \tag{26}$$

$$Min\,\tilde{Z}_3(x)=\sum_{l=1}^{g+h}\sum_{p=1}^{g+h}\sum_{k=1}^{K}\Re(\tilde{d}_{lpk})x_{lpk} \tag{27}$$

Subject to

$$\sum_{p=1,l\neq p}^{g+h}\sum_{k=1}^{K}x_{lpk}-\sum_{l=1,l\neq p}^{g+h}\sum_{k=1}^{K}x_{plk}\leq\Re(\tilde{a}_l),\quad l=1,2,3,\ldots,g \tag{28}$$

$$\sum_{l=1,l\neq p}^{g+h}\sum_{k=1}^{K}(1-\Re(\tilde{d}_{lpk}))x_{lpk}-\sum_{l=1,l\neq p}^{g+h}\sum_{k=1}^{K}(1-\Re(\tilde{d}_{lpk}))x_{plk}\geq\Re(\tilde{b}_p),\quad p=g+1,g+2,\ldots,g+h \tag{29}$$

$$\sum_{l=1}^{g+h}\sum_{p=1}^{g+h}x_{lpk}\leq\Re(\tilde{e}_k),k=1,2,3,\ldots K \tag{30}$$

$$\eta_{ü}\ =\begin{cases}0 & ü\ \ _{ü}=0\\ 1 & ü\ \ _{ü}>0\end{cases} \tag{31}$$

$$x_{lpk},\eta_{lpk}\geq 0,l,p=1,2,3,\ldots,g+h,k=1,2,\ldots,K \tag{32}$$

Solution Procedure

To obtain the optimum solution for this above deterministic model, Weighted tchebycheff metrics programming is used in this paper as follows

Weighted Tchebycheff Metrics Programming

This optimization approach uses weighted distance metrics to find the compromise solution for multi-objective linear programming problems. Identifying the feasible solution that is nearest to an ideal solution is the fundamental concept of this method. Distance between ideal and feasible points is determined by using L_u metric is the most prevalent metric which is defined as $L_u = \left[\sum_{K=1}^{3}\left(\frac{w_k(Z_k - Z_k^{\min})}{Z_k^{\max} - Z_k^{\min}}\right)\right]^{\frac{1}{u}}, 1 \le u < \infty.$ If $u \to \infty$ then L_u denotes as Tchebycheff metric (Midya and Roy 2021).

When $u = 1$, the Manhattan metric is obtained; when $u = 2$, the Euclidean metric is defined; and $u \to \infty$ then, Tchebychef metric is approached. To derive a Pareto-optimal solution, the weighted ∞-norm (L_∞) as the distance metric can be used. This approach is commonly referred to as weighted Tchebychef metric programming. The mathematical model of weighted Tchebychef metrics for deriving the Pareto-optimal solution of the deterministic multi-objective solid transshipment problem with and without preservation technology is described below.

P1: with preservation technology

Minimize α

Subject to Constraints

$$\alpha \ge \frac{w_k(Z_k - Z_k^{\min})}{Z_k^{\max} - Z_k^{\min}} \forall k = 1,2,...,K$$

$$\sum_{k=1}^{K} \ddot{u}_k \ \aleph\ddot{u} \quad {}_k$$

$$\sum_{p=1, l \ne p}^{g+h} \sum_{k=1}^{K} x_{lpk} - \sum_{l=1, l \ne p}^{g+h} \sum_{k=1}^{K} x_{plk} \le \Re(\tilde{a}_l), \quad l = 1,2,3,\ldots,g$$

$$\sum_{l=1, l \ne p}^{g+h} \sum_{k=1}^{K} (1 - \beta_z \Re(\tilde{d}_{lpk})) x_{lpk} - \sum_{l=1, l \ne p}^{g+h} \sum_{k=1}^{K} (1 - \beta_z \Re(\tilde{d}_{lpk})) x_{plk} \ge \Re(\tilde{b}_p), \quad p = g+1, g+2, \ldots, g+h$$

$$\sum_{l=1}^{g+h} \sum_{p=1}^{g+h} x_{lpk} \le \Re(\tilde{e}_k), k = 1,2,3,...K$$

$$\eta_{\ddot{u}} \quad = \begin{cases} 0 & \ddot{u} \quad {}_{\ddot{u}} \ = 0 \\ 1 & \ddot{u} \quad {}_{\ddot{u}} \ > 0 \end{cases}$$

$$x_{lpk}, \eta_{lpk} \ge 0, l, p = 1,2,3,\ldots, g+h, k = 1,2,...,K$$

$$\alpha \ge 0$$

P2: without preservation technology

Minimize α

Subject to Constraints

$$\alpha \ge \frac{w_k(Z_k - Z_k^{\min})}{Z_k^{\max} - Z_k^{\min}} \forall k = 1,2,...,K$$

$$\sum_{k=1}^{K} \ddot{u}_k \ \aleph\ddot{u} \quad {}_k$$

$$\sum_{p=1, l \ne p}^{g+h} \sum_{k=1}^{K} x_{lpk} - \sum_{l=1, l \ne p}^{g+h} \sum_{k=1}^{K} x_{plk} \le \Re(\tilde{a}_l), \quad l = 1,2,3,\ldots,g$$

$$\sum_{l=1, l \ne p}^{g+h} \sum_{k=1}^{K} (1 - \Re(\tilde{d}_{lpk})) x_{lpk} - \sum_{l=1, l \ne p}^{g+h} \sum_{k=1}^{K} (1 - \Re(\tilde{d}_{lpk})) x_{plk} \ge \Re(\tilde{b}_p), \quad p = g+1, g+2, \ldots, g+h$$

$$\sum_{l=1}^{g+h} \sum_{p=1}^{g+h} x_{lpk} \le \Re(\tilde{e}_k), k = 1,2,3,...K$$

$$\eta_{\ddot{u}} \quad = \begin{cases} 0 & \ddot{u} \quad {}_{\ddot{u}} \ = 0 \\ 1 & \ddot{u} \quad {}_{\ddot{u}} \ > 0 \end{cases}$$

$$x_{lpk}, \eta_{lpk} \ge 0, l, p = 1,2,3,\ldots, g+h, k = 1,2,...,K$$

$$\alpha \ge 0$$

Finally, the optimal solution of the proposed model is obtained using the LINGO Software (20.0).

Result

In this section, the applicability of the described model is demonstrated by using a relevant real-life example to evaluate the efficiency of the preservation technology in the transshipment problem for transporting perishable products throughout the entire distribution system. Previous research has explored the preservation technology in transportation problems to reduce the deterioration rate. However, transshipment plays a significant role during emergency situations to transport fresh products. In this study, a multi-objective solid transshipment problem with preservation technology has been investigated which is not yet discussed in existing literature.

Numerical Example

Consider the numerical example given in which the reputed company transports the various types of fishes from two sources located at West Bengal and Odisha in India to two different demand points located at Punjab and Himachal Pradesh in India (Ghosh *et al*., 2022). Assume that, the company is used Preservation Technology to minimize the deterioration rate of items during transportation. As transshipment model plays crucial role during emergency, hence consider the given transportation problem into transshipment to discuss the reduction of the optimal transportation costs, preservation costs, transportation time, and the deterioration rate throughout the entire transshipment process. Transportation costs are measured in rupees per ton, while the deterioration rate is represented as a percentage. Transportation time is measured in hour. Preservation cost, in rupees, is determined by factors such as transportation time, the quantity of items, and the preservation method. Source, demand, conveyance, transportation cost, preservation cost, transportation time, and deterioration rate are presented as Pythagorean fuzzy number in this existing literature. To handle the inconsistent and intermediate information, source, demand, conveyance, transportation cost, preservation cost, transportation time, and deterioration rate are defined as TrNsNN in this proposed transshipment model and they are presented in [Tables 1-5.]. The decision maker wants to transport a quantity of items from l^{th} source to p^{th} destination at k^{th} conveyance to satisfy the total requirement. All the fuzzy parameters are converted into crisp numbers using a ranking operator, and then two models are formulated.

Table 1: Transportation cost $\tilde{c}_{lpk}\,(l=1,2,3,4\ ;\ p=1,2,3,4; k=1,2)$ in dollar

$\tilde{c}_{\text{ü}}$	$\langle(4.5,6.5,7.5,8.5);0.5,0.3,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(3.75,4.75,6.25,7.75);0.6,0.4,0.2\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(4.75,6.75,7.25,9.75);0.5,0.3,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(15.4,20.8,25.8,30.4);0.6,0.4,0.2\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(13.9,18.7,22.7,27.9);0.5,0.4,0.1\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(10.4,14.2,16.4,21.4);0.6,0.3,0.3\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(4.5,6.5,7.5,8.5);0.5,0.3,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(3.75,4.75,6.25,7.75);0.6,0.4,0.2\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(11,13,18,24);0.5,0.3,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(12.8,15.8,21.4,26.8);0.7,0.4,0.3\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(20.6,27.8,34.6,40.6);0.4,0.2,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(17.75,25,29,34.75);0.6,0.4,0.2\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(4.75,6.75,7.25,9.75);0.5,0.3,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(15.4,20.8,25.8,30.4);0.6,0.4,0.2\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(11,13,18,24);0.5,0.3,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(12.8,15.8,21.4,26.8);0.7,0.4,0.3\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(0.6,0.8,1,1.2);0.6,0.4,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(0.5,0.65,0.85,1);0.5,0.3,0.2\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(13.9,18.7,22.7,27.9);0.5,0.4,0.1\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(10.4,14.2,16.4,21.4);0.6,0.3,0.3\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(20.6,27.8,34.6,40.6);0.4,0.2,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(17.75,25,29,34.75);0.6,0.4,0.2\rangle$
$\tilde{c}_{\text{ü}}$	$\langle(0.6,0.8,1,1.2);0.6,0.4,0.2\rangle$	$\tilde{c}_{\text{ü}}$	$\langle(0.5,0.65,0.85,1);0.5,0.3,0.2\rangle$

Table 2: Preservation cost $\tilde{p}_{lpk}\,(l=1,2,3,4\ ;\ p=1,2,3,4; k=1,2)$ in dollar

$\tilde{p}_{\text{ü}}$	$\langle(8.5,11.5,14.5,16.5);0.4,0.3,0.1\rangle$	$\tilde{p}_{\text{ü}}$	$\langle(11.5,15.5,18.5,23.5);0.5,0.3,0.2\rangle$
$\tilde{p}_{\text{ü}}$	$\langle(6.5,8.5,10.5,13.5);0.6,0.3,0.3\rangle$	$\tilde{p}_{\text{ü}}$	$\langle(5.75,7.75,9.75,11.25);0.5,0.4,0.1\rangle$
$\tilde{p}_{\text{ü}}$	$\langle(10.5,13.5,16.5,22.5);0.7,0.5,0.2\rangle$	$\tilde{p}_{\text{ü}}$	$\langle(7.25,9,12,15.25);0.8,0.5,0.3\rangle$
$\tilde{p}_{\text{ü}}$	$\langle(8.5,11.5,14.5,16.5);0.4,0.3,0.1\rangle$	$\tilde{p}_{\text{ü}}$	$\langle(11.5,15.5,18.5,23.5);0.5,0.3,0.2\rangle$
$\tilde{p}_{\text{ü}}$	$\langle(12.8,16.8,20.8,26.4);0.5,0.3,0.2\rangle$	$\tilde{p}_{\text{ü}}$	$\langle(14.5,18.5,24.5,29.5);0.7,0.5,0.2\rangle$
$\tilde{p}_{\text{ü}}$	$\langle(10,13,17,20);0.4,0.3,0.1\rangle$	$\tilde{p}_{\text{ü}}$	$\langle(7.25,9,12,15.25);0.8,0.5,0.3\rangle$

$\tilde{p}_{ü}$	$\langle(6.5, 8.5, 10.5, 13.5); 0.6, 0.3, 0.3\rangle$	$\tilde{p}_{ü}$	$\langle(5.75, 7.75, 9.75, 11.25); 0.5, 0.4, 0.1\rangle$
$\tilde{p}_{ü}$	$\langle(12.8, 16.8, 20.8, 26.4); 0.5, 0.3, 0.2\rangle$	$\tilde{p}_{ü}$	$\langle(14.5, 18.5, 24.5, 29.5); 0.7, 0.5, 0.2\rangle$
$\tilde{p}_{ü}$	$\langle(1, 1, 2, 2); 0.4, 0.2, 0.2\rangle$	$\tilde{p}_{ü}$	$\langle(1, 2, 3, 6); 0.6, 0.4, 0.2\rangle$
$\tilde{p}_{ü}$	$\langle(10.5, 13.5, 16.5, 22.5); 0.7, 0.5, 0.2\rangle$	$\tilde{p}_{ü}$	$\langle(7.25, 9, 12, 15.25); 0.8, 0.5, 0.3\rangle$
$\tilde{p}_{ü}$	$\langle(10, 13, 17, 20); 0.4, 0.3, 0.1\rangle$	$\tilde{p}_{ü}$	$\langle(4, 12, 22, 24); 0.4, 0.3, 0.1\rangle$
$\tilde{p}_{ü}$	$\langle(1, 1, 2, 2); 0.4, 0.2, 0.2\rangle$	$\tilde{p}_{ü}$	$\langle(1, 2, 3, 6); 0.6, 0.4, 0.2\rangle$

Table 3: Deterioration rate $\tilde{d}_{lpk} (l = 1,2,3,4\ ; p = 1,2,3,4; k = 1,2)$ in %

$\tilde{d}_{ü}$	$\langle(1.75, 2, 2.75, 3.5); 0.6, 0.4, 0.2\rangle$	$\tilde{d}_{ü}$	$\langle(1.63, 2, 2.6, 3.55); 0.4, 0.2, 0.2\rangle$
$\tilde{d}_{ü}$	$\langle(7.5, 9.5, 12.5, 15.5); 0.7, 0.4, 0.3\rangle$	$\tilde{d}_{ü}$	$\langle(6.5, 8.5, 10.5, 13.5); 0.5, 0.3, 0.2\rangle$
$\tilde{d}_{ü}$	$\langle(8.5, 10.5, 14.5, 17.5); 0.8, 0.5, 0.3\rangle$	$\tilde{d}_{ü}$	$\langle(3.5, 4.5, 5.5, 7.5); 0.5, 0.3, 0.2\rangle$
$\tilde{d}_{ü}$	$\langle(1.75, 2, 2.75, 3.5); 0.6, 0.4, 0.2\rangle$	$\tilde{d}_{ü}$	$\langle(1.63, 2, 2.6, 3.55); 0.4, 0.2, 0.2\rangle$
$\tilde{d}_{ü}$	$\langle(3.5, 4.5, 5.5, 7.5); 0.5, 0.3, 0.2\rangle$	$\tilde{d}_{ü}$	$\langle(3.75, 4.75, 6.25, 7.75); 0.6, 0.4, 0.2\rangle$
$\tilde{d}_{ü}$	$\langle(7.75, 9.25, 11.25, 15.25); 0.8, 0.5, 0.3\rangle$	$\tilde{d}_{ü}$	$\langle(10, 13, 17, 20); 0.4, 0.3, 0.1\rangle$
$\tilde{d}_{ü}$	$\langle(7.5, 9.5, 12.5, 15.5); 0.7, 0.4, 0.3\rangle$	$\tilde{d}_{ü}$	$\langle(6.5, 8.5, 10.5, 13.5); 0.5, 0.3, 0.2\rangle$
$\tilde{d}_{ü}$	$\langle(3.5, 4.5, 5.5, 7.5); 0.5, 0.3, 0.2\rangle$	$\tilde{d}_{ü}$	$\langle(3.75, 4.75, 6.25, 7.75); 0.6, 0.4, 0.2\rangle$
$\tilde{d}_{ü}$	$\langle(0.4, 0.5, 0.6, 0.9); 0.5, 0.3, 0.2\rangle$	$\tilde{d}_{ü}$	$\langle(1, 1, 2, 2); 0.4, 0.2, 0.2\rangle$
$\tilde{d}_{ü}$	$\langle(8.5, 10.5, 14.5, 17.5); 0.8, 0.5, 0.3\rangle$	$\tilde{d}_{ü}$	$\langle(3.5, 4.5, 5.5, 7.5); 0.5, 0.3, 0.2\rangle$
$\tilde{d}_{ü}$	$\langle(7.75, 9.25, 11.25, 15.25); 0.8, 0.5, 0.3\rangle$	$\tilde{d}_{ü}$	$\langle(10, 13, 17, 20); 0.4, 0.3, 0.1\rangle$
$\tilde{d}_{ü}$	$\langle(0.4, 0.5, 0.6, 0.9); 0.5, 0.3, 0.2\rangle$	$\tilde{d}_{ü}$	$\langle(1, 1, 2, 2); 0.4, 0.2, 0.2\rangle$

Optimal solution and comparative study

By using a method prescribed in 2.3.1, the obtained optimum solutions of deterministic multi-objective solid transshipment problem with and without preservation technology using Lingo Global Solver (20.0) are presented in [Table 6.]. Consequently, the comparison between multi-objective solid transshipment and transportation problems with and without preservation technology is detailed in [Table 7.]. Also, a comparison between multi-objective solid transportation problems with and without preservation technology under neutrosophic and Pythagorean fuzzy environments is presented in [Table 7.].

Table 4: Transportation time $\tilde{t}_{ij}(l=1,2,3,4 \text{ and } p=1,2,3,4)$ in Hours

$\tilde{t}_{ü}$	$\langle(6.9,8.9,11.7,13.9);0.5,0.3,0.2\rangle$	$\tilde{t}_{ü}$	$\langle(5.7,7.7,9.7,11.1);0.5,0.3,0.2\rangle$
$\tilde{t}_{ü}$	$\langle(25.25,35.25,40.25,50.75);0.6,0.4,0.2\rangle$	$\tilde{t}_{ü}$	$\langle(23,30,37,48);0.6,0.3,0.3\rangle$
$\tilde{t}_{ü}$	$\langle(26.5,34.5,42.5,55.5);0.7,0.4,0.2\rangle$	$\tilde{t}_{ü}$	$\langle(10,13,17,20);0.4,0.3,0.1\rangle$
$\tilde{t}_{ü}$	$\langle(6.9,8.9,11.7,13.9);0.5,0.3,0.2\rangle$	$\tilde{t}_{ü}$	$\langle(5.7,7.7,9.7,11.1);0.5,0.3,0.2\rangle$
$\tilde{t}_{ü}$	$\langle(12.6,16.8,20.6,25.6);0.5,0.2,0.3\rangle$	$\tilde{t}_{ü}$	$\langle(15.8,20.8,25.8,32.8);0.7,0.4,0.3\rangle$
$\tilde{t}_{ü}$	$\langle(24,32,40,48);0.5,0.4,0.1\rangle$	$\tilde{t}_{ü}$	$\langle(25,30,37,45);0.6,0.4,0.2\rangle$
$\tilde{t}_{ü}$	$\langle(25.25,35.25,40.25,50.75);0.6,0.4,0.2\rangle$	$\tilde{t}_{ü}$	$\langle(23,30,37,48);0.6,0.3,0.3\rangle$
$\tilde{t}_{ü}$	$\langle(12.6,16.8,20.6,25.6);0.5,0.2,0.3\rangle$	$\tilde{t}_{ü}$	$\langle(16,32,48,71);0.5,0.3,0.2\rangle$
$\tilde{t}_{ü}$	$\langle(3.7,4.7,5.7,8.1);0.6,0.4,0.2\rangle$	$\tilde{t}_{ü}$	$\langle(4.5,6,7.5,9);0.5,0.4,0.1\rangle$
$\tilde{t}_{ü}$	$\langle(26.5,34.5,42.5,55.5);0.7,0.4,0.2\rangle$	$\tilde{t}_{ü}$	$\langle(10,13,17,20);0.4,0.3,0.1\rangle$
$\tilde{t}_{ü}$	$\langle(24,32,40,48);0.5,0.4,0.1\rangle$	$\tilde{t}_{ü}$	$\langle(25,30,37,45);0.6,0.4,0.2\rangle$
$\tilde{t}_{ü}$	$\langle(3.7,4.7,5.7,8.1);0.6,0.4,0.2\rangle$	$\tilde{t}_{ü}$	$\langle(4.5,6,7.5,9);0.5,0.4,0.1\rangle$

Table 5: Supply and demand $\tilde{a}_l(l=1,2)$ and $\tilde{b}_p(p=3,4)$ in ton

$\tilde{a}_1=\langle(200,400,600,800);0.5,0.4,0.1\rangle$	$\tilde{b}_1=\langle(100,300,500,700);0.4,0.2,0.2\rangle$
$\tilde{a}_2=\langle(250,450,650,850);0.4,0.2,0.2\rangle$	$\tilde{b}_2=\langle(200,220,300,400);0.2,0.3,0.1\rangle$

Table 6: Optimum solutions for multi-objective solid transshipment problem with preservation technology and without technology

Model	*Multi-objective solid transhipment problem with preservation technology*	*Multi-objective solid transhipment problem without preservation technology*
Weighted Tchebycheff metrics programming	$\Re(\tilde{Z}_1)=\$6688.3$, $\Re(\tilde{Z}_2)=47.85h$ $\Re(\tilde{Z}_3)=0.85\%$	$\Re(\tilde{Z}_1)=\$4401.46$, $\Re(\tilde{Z}_2)=47.85h$, $\Re(\tilde{Z}_3)=18.26\%$

Table 7: Comparison table for transportation and transshipment problem

	With PT	*Without PT*
Multi-objective solid transportation problem under Pythagorean fuzzy environment by Ghosh S, Roy SK	$\Re(\tilde{Z}_1) = \$6859.66$, $\Re(\tilde{Z}_2) = 61h$, $\Re(\tilde{Z}_3) = 0.94\%$	$\Re(\tilde{Z}_1) = \$4611.63$, $\Re(\tilde{Z}_2) = 61h$, $\Re(\tilde{Z}_3) = 19.75\%$
Multi-objective solid transportation problem under neutrosophic Environment	$\Re(\tilde{Z}_1) = \$6767.68$, $\Re(\tilde{Z}_2) = 59.25h$ $\Re(\tilde{Z}_3) = 0.86\%$	$\Re(\tilde{Z}_1) = \$4591.45$, $\Re(\tilde{Z}_2) = 59.25h$ $\Re(\tilde{Z}_3) = 18.26\%$
Multi-objective solid transhipment problem under neutrosophic environment	$\Re(\tilde{Z}_1) = \$6688.3$, $\Re(\tilde{Z}_2) = 47.85h$ $\Re(\tilde{Z}_3) = 0.85\%$	$\Re(\tilde{Z}_1) = \$4401.46$, $\Re(\tilde{Z}_2) = 47.85h$, $\Re(\tilde{Z}_3) = 18.26\%$

Discussion

Gosh *et al*., (2022) introduced the idea of PT within MOSTP based on a Pythagorean fuzzy environment. The practical relevance of PT in TP is found in the fact that it is very significant, as the overall cost of transportation varies, if the effect of PT increases or decreases, and there is a trade-off between the increased cost and decreased rate of deterioration. As a result, the items can be sold for a higher price, increasing the profit and recovering the economic loss.

Baskaran *et al*., (2016) calculate the quantities that should be shipped from each source to each destination in order to meet demand requirements and supply constraints while minimizing the overall cost of shipping.

Akram *et al*., (2022) developed the MOTP in a fuzzy Fermatean setting. Next, we have created a method based on FFDEA for resolving the FFMOTP.

Conclusion

Deterioration is one of the significant disadvantages when transport perishable item in the transshipment problem. Introducing preservation technology in transshipment problem will help mitigate these impacts effectively. Due to uncertainty in the real-world scenario, the proposed model has been formulated under neutrosophic fuzzy environment. Pareto optimum solutions have been obtained using weighted Tchebycheff metrics programming through Lingo Software package. The case study has been discussed for multi-objective solid transshipment problem with and without Preservation technology. From the obtained solutions, there is a significant difference in the value of deterioration rate between preservation technology and without preservation technology. The optimum solutions for multi-objective solid transshipment problems with preservation technology show a reduction of 95% in deterioration than the ordinary transshipment problem. Consequently, obtained solutions for the multi-objective solid transshipment problem show that 1.18% in cost, 23.82% in time and 0.01% in deterioration than the existing multi-objective transportation problem. Also, the multi-objective solid transportation problem with and without preservation technology under a neutrosophic fuzzy environment shows a minimum transportation cost, time, and deterioration rate than the Pythagorean fuzzy environment. The proposed model may be extended by integrating essential environmental factors and social factors to enhance sustainability in the future direction.

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Nil.

Conflicts of Interest

The authors declare no conflict of interest.

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